Chapter 2

Power Distribution

Power Distribution

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1. SUPPLY VOLTAGES

In the cement industry, the supply voltages from the utility power companies are in the range of:

- 11 kV (for small plants)
  up to
- 150 kV (for large plants)

In power distribution systems we distinguish between equipment for:

- 'high voltage' > 50 kV
- 'medium voltage' 1-50 kV
- 'low voltage' ≥ 1 kV

The design of the equipment (e.g. circuit breaker) varies according to the requirements of the different voltage levels and power ratings.

Note: The medium voltage range is very often also called 'high voltage', e.g. 6 kV high voltage motors.

2. HIGH VOLTAGE TRANSFORMER STATION

Depending on the layout of the cement plant and on the type of switchgear installed this station is located on the periphery or in the centre of a cement plant. For safety reasons a cement plant is preferably fed by two incoming cables or overhead lines. The transmission, voltage can vary between 11 kV and 150 kV and is normally fixed by the power supplier. The high voltage will be transformed to 4 to 11 kV by means of preferably two transformers, one of as stand-by.

For power distribution system-arrangement see Fig. 2.1. For power distribution single line diagram see Fig. 2.2.

Figure 2.1 Example of a Power Distribution System-Arrangement

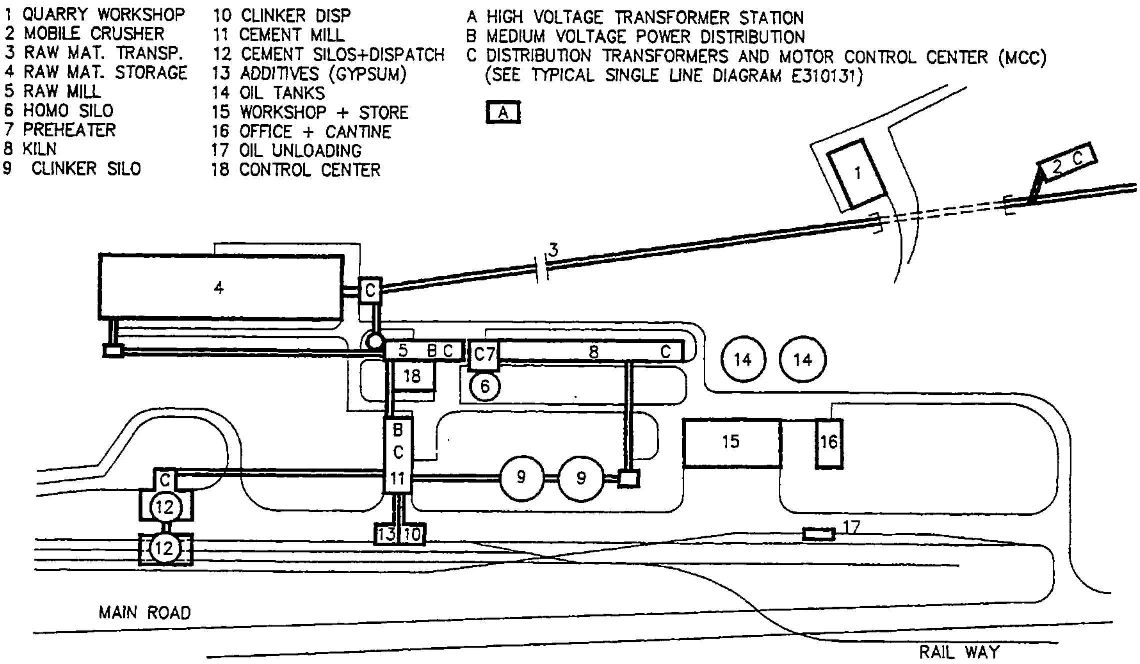
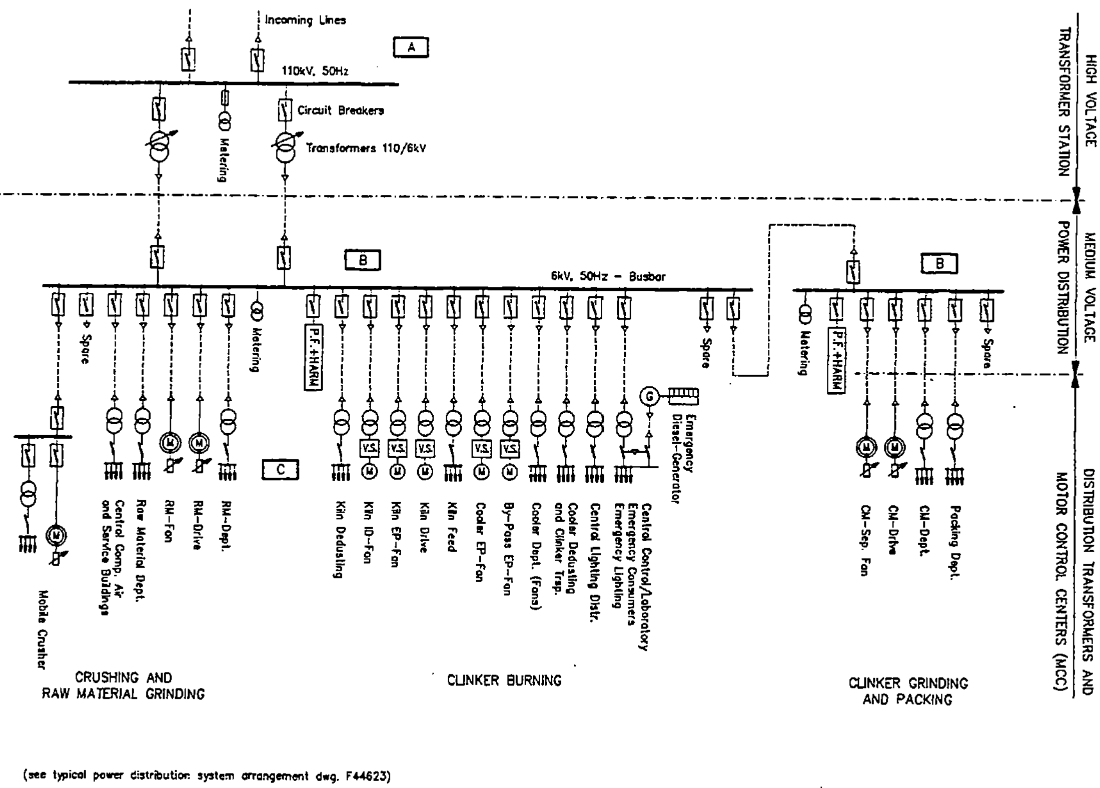


Figure 2.2 Example of a Power Distribution Single Line Diagram



3. MEDIUM VOLTAGE POWER DISTRIBUTION

The medium voltage power distribution is usually located in an electrical room in the centre of a cement plant, this is order to minimise cabling and installation costs (centralised MV-distribution).

However, depending on the layout of the plant, the MV-power distribution may be arranged in a decentralised manner, i.e. the MV-distribution might be located in load centres common with the LV-distribution transformers and motor control centres. For comparison of 'centralised' and 'decentralised' arrangements refer to single line diagram Fig. 3.1.

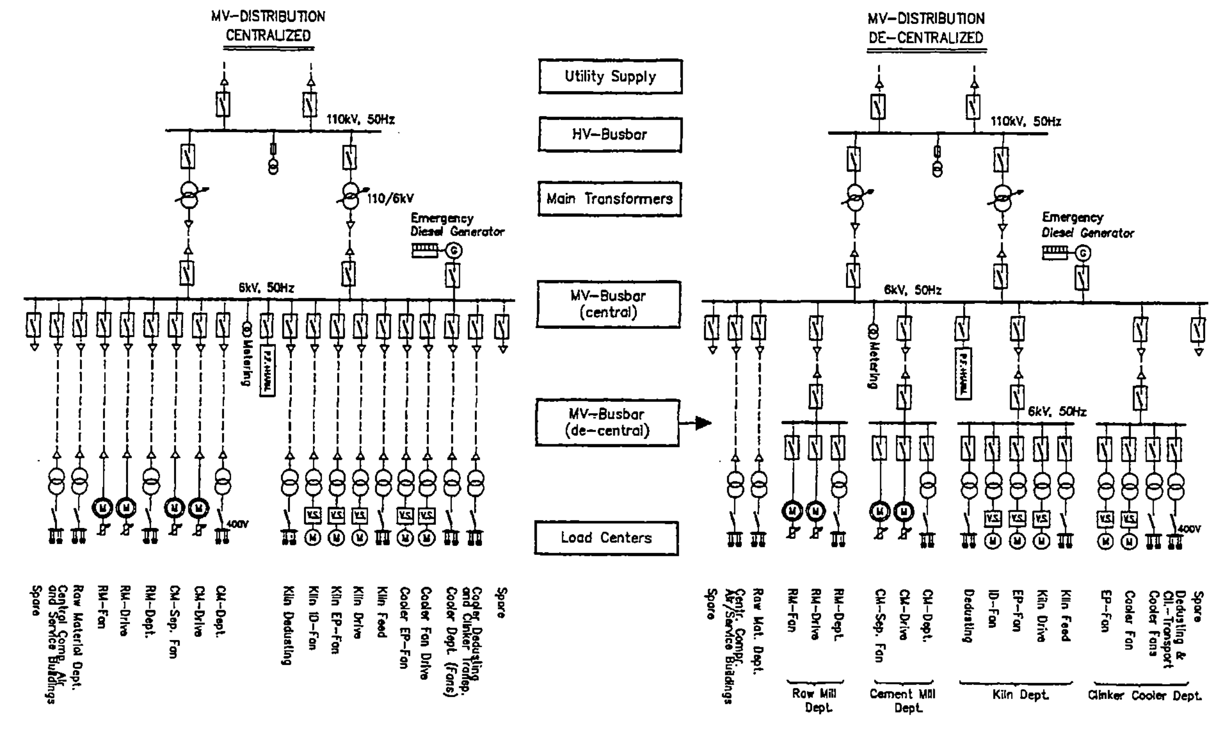
Decentralised arrangements may result in the application of a higher quantity of circuit breakers, control equipment, larger electrical rooms, a more sophisticated protection scheme and requires a somewhat more costly maintenance. Costs for MV-cabling may however be smaller.

The medium voltage level normally ranges from 4 kV up to 11 kV. There is a strong tendency to use the higher voltage of 11 kV; 50 Hz, resp. 13.8 kV; 60 Hz, because a higher working voltage results in smaller cable cross-sections (i.e. lower investment costs) and less voltage drops (i.e. less energy losses).

The distribution station is equipped with a main busbar, the incoming circuit breakers and the different outgoing circuit breakers to the distribution transformers and 'high voltage' motors. Distribution transformer stations are located in the different load centres, namely the crushing plant, the raw meal grinding plant, the kiln plant, the cement grinding plant and the packing plant.

All high and medium voltage equipment (transformers, cables and motors) has to be protected against overload, short circuit, earth fault, over voltage, etc. to guarantee a selective fault isolation.

Figure 3.1 Centralised & de-centralised medium voltage distribution typical single-line-diagram



Load Centers: Contain Distribution Transformers, Motor Control Centers, VS-Motor Controls, etc.

4. DISTRIBUTION TRANSFORMERS AND MOTOR CONTROL CENTRES (MCC)

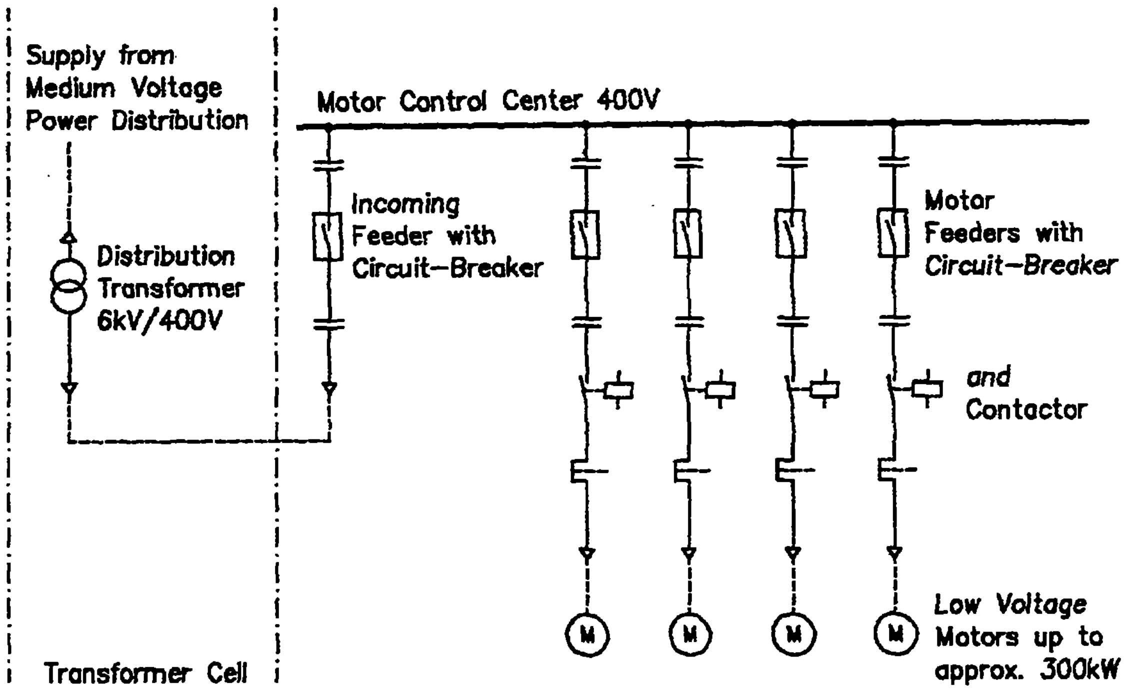
Distribution transformers and MCC's are located in the different load centres of the plant.

The transformers have a capacity of 630 up to 2000 kVA depending on the power requirement and a low voltage level of 400 V up to 660 V.

Distribution transformers are normally installed indoors in individual transformer cells.

The low voltage switch gear and MCC's are located in electrical rooms of the respective plant buildings.

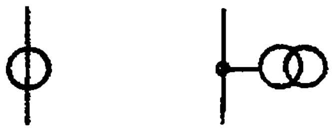
Figure 4.1 Single line diagram
'Example of a load centre with distribution transformer and MCC'



5. HIGH VOLTAGE EQUIPMENT

The high voltage transformer station generally consists of following components:

Lightning arrestors (protect the substation against over voltage such as lightning)



Current and voltage transformers (measure the amount of energy consumed)

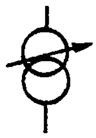
Off-load isolator (isolate a circuit at no load e.g. for maintenance purposes)

On-load isolator (disconnect a circuit at max. double-rated current)

Earthing switches (connect a circuit to the earth for safety reasons, during maintenance activities)

Circuit breakers (disconnect a circuit under load and in case of fault)

Busbars (form the electrical power circuit)



Step-down transformer (transforms incoming voltage to the plant power distribution level e.g. 110 kV to 7 kV)

The following 3 types of transformer stations are mainly used:

- Outdoor transformer station with conventional switch gear:

  Characteristics:
  - biggest surface area required
  - medium investment costs for high voltage switch gear
  - time consuming for maintenance (cleaning)

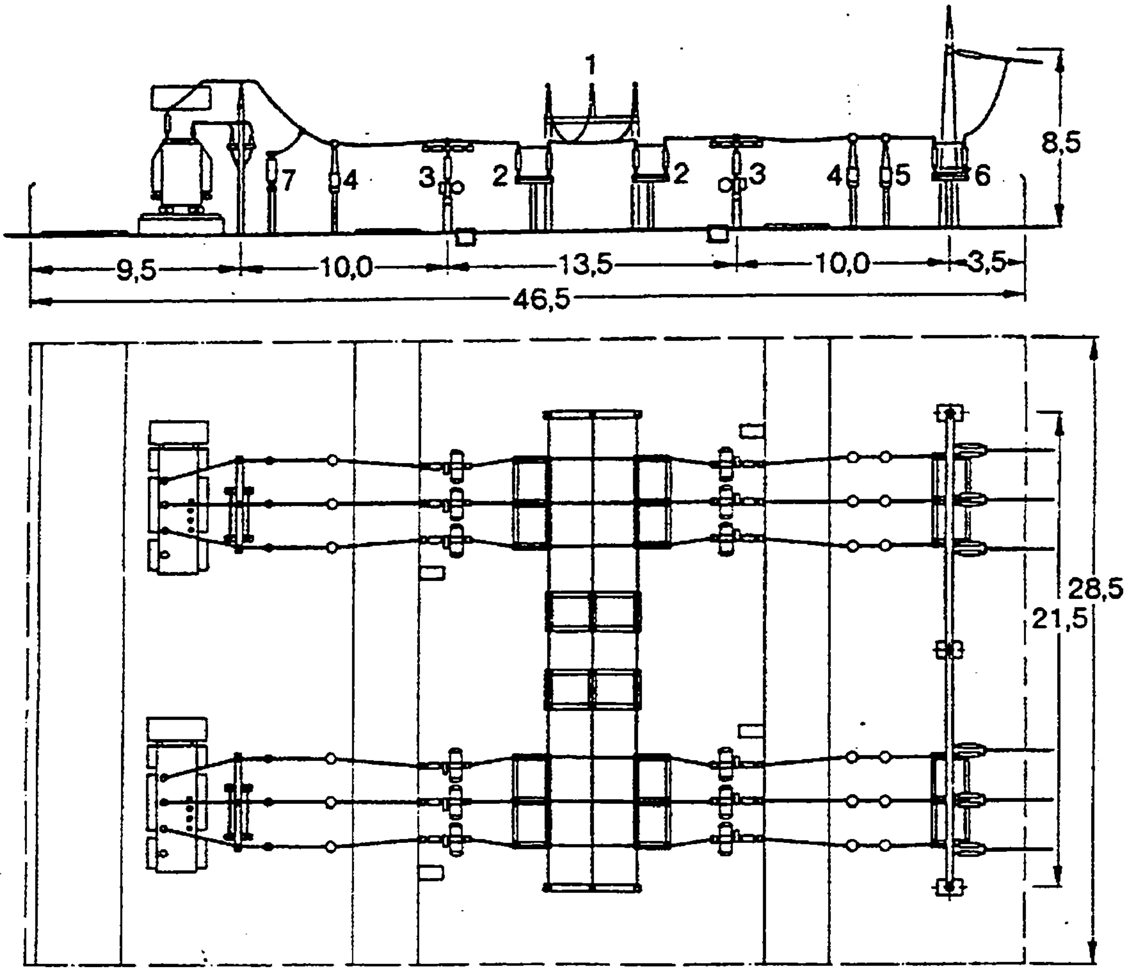
- Indoor transformer station with conventional switch gear:

  Characteristics:
  - medium surface area required
  - lowest investment costs for high voltage switch gear
  - medium time required for maintenance

- Indoor transformer station with metal-clad, SF_6, gas insulated or vacuum type switch gear:

  Characteristics:
  - smallest surface area required
  - highest investment costs for high voltage
  - switch gear
  - needs the least of maintenance

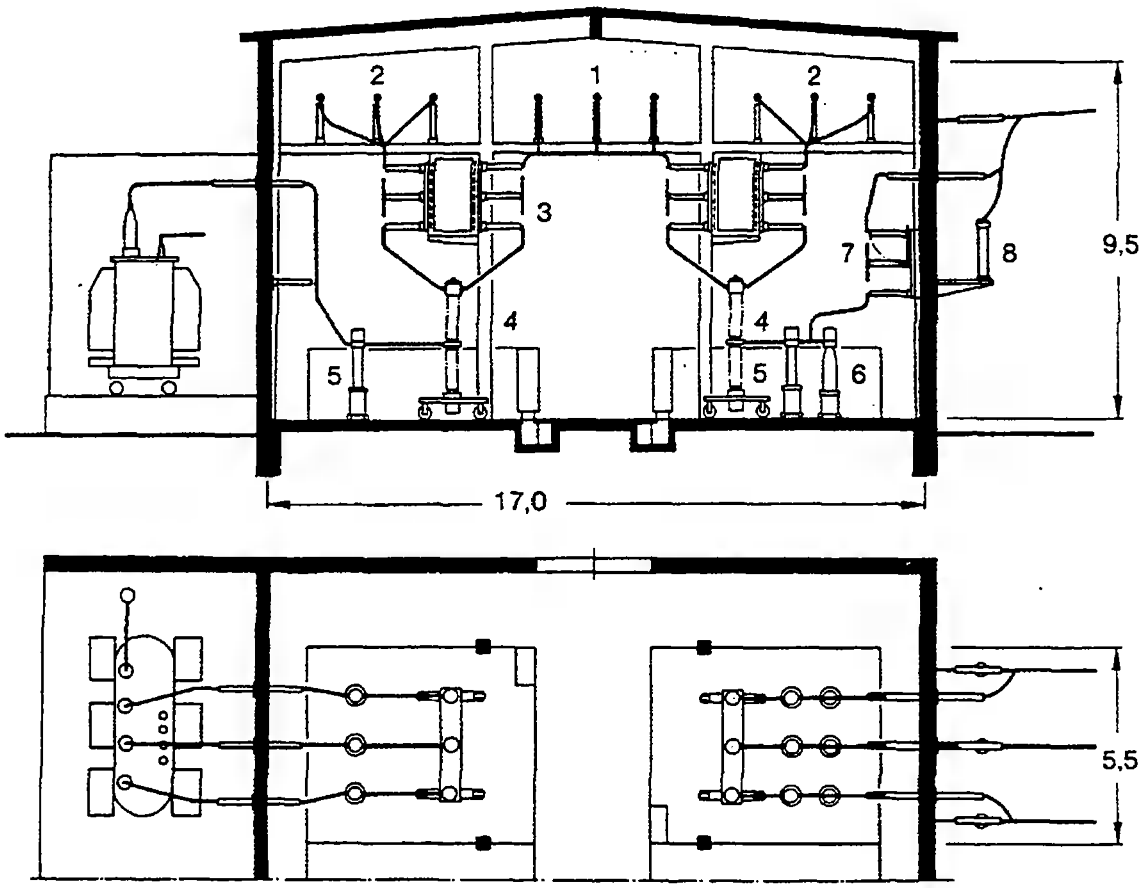
Figure 5.0.1 110 kV Outdoor Transformer Station
Typical arrangement with conventional switch gear



Legend:

1	Busbar system
2,6	Off-load isolator
3	Circuit breaker
4	Current transformer
5	Voltage transformer
7	Lightning arrestor
8	Power transformer

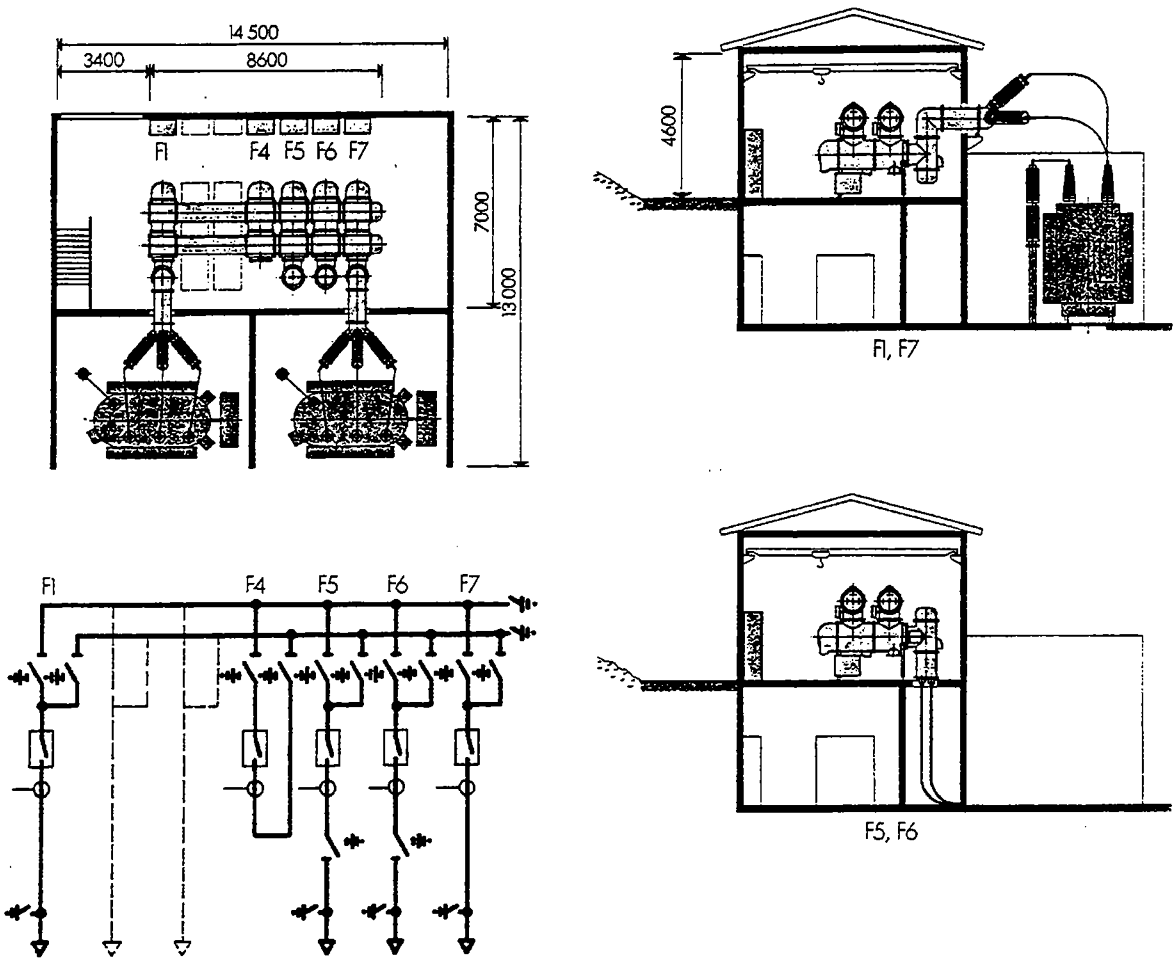
**Figure 5.0.2 110 kV Indoor Transformer Station
Typical arrangement with conventional switch gear**



Legend:

1, 2	Busbar systems (double busbars)
3, 7	Off-load isolator
4	Circuit breaker
5	Current transformer
6	Voltage transformer
8	Lightning arrestor
9	Power transformer

Figure 5.0.3 110 kV Indoor Transformer Station
Typical arrangement with metal-clad, SF_6 gas insulated switch gear



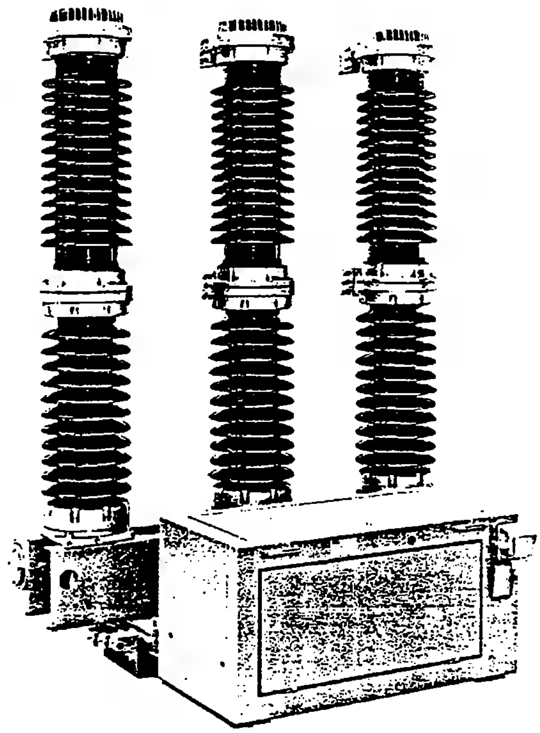
Legend:

F5, F6	Incoming feeders consisting of off-load isolators, circuit breaker, earthing switches, current and voltage transformers
F1, F7	Outgoing feeders consisting of off-load isolators, circuit breaker, earthing switches, current transformers
F4	Buscoupler (double busbars)

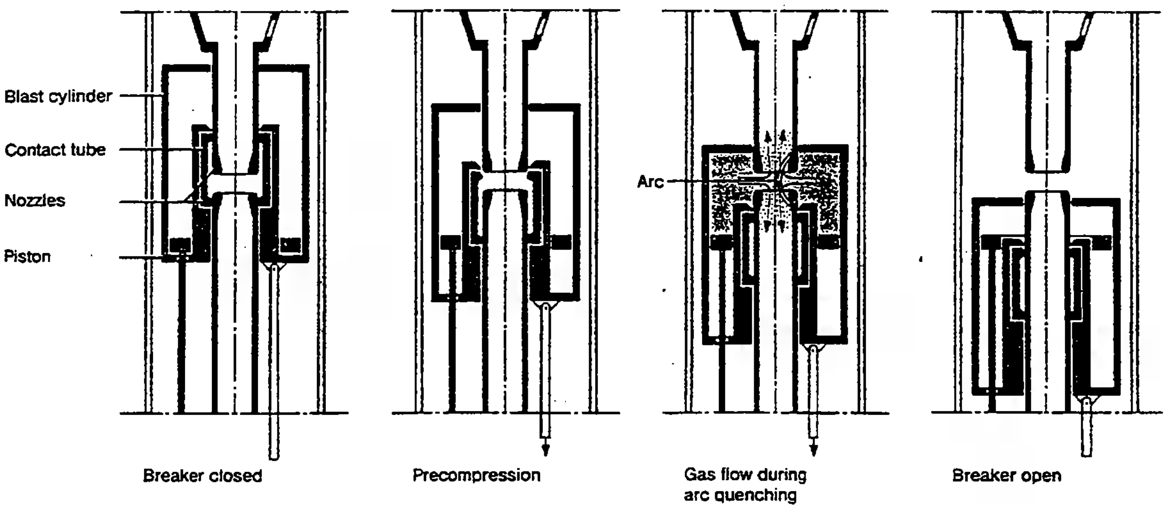
5.1 Circuit Breakers

In high voltage installations mostly SF_6 gas circuit breakers are applied. The low oil content circuit breakers are still used but manufacturing will run out in the next years.

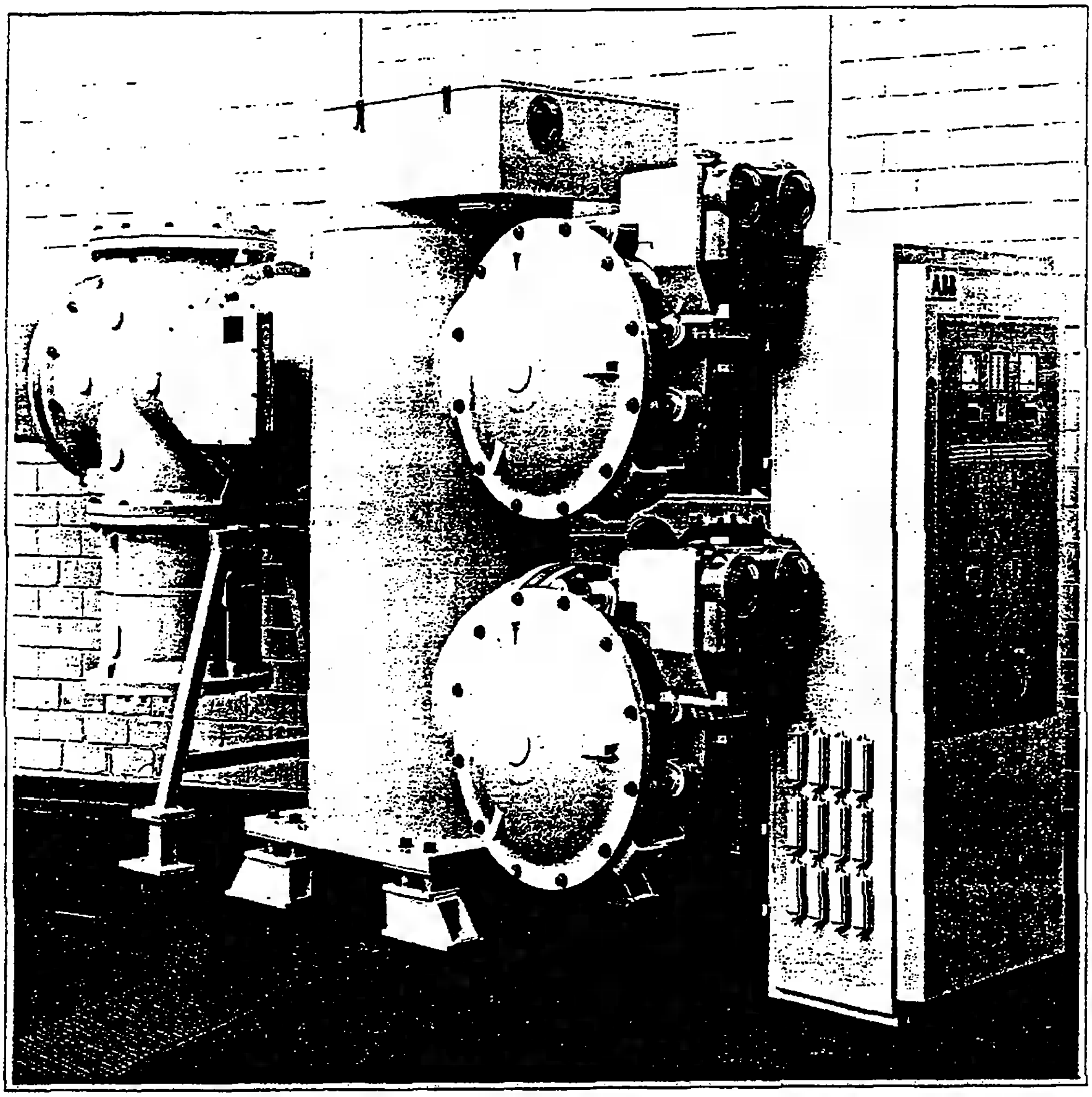
Figure 5.1.1 SF6 Gas Circuit Breaker
3-pole circuit breaker with operating mechanism



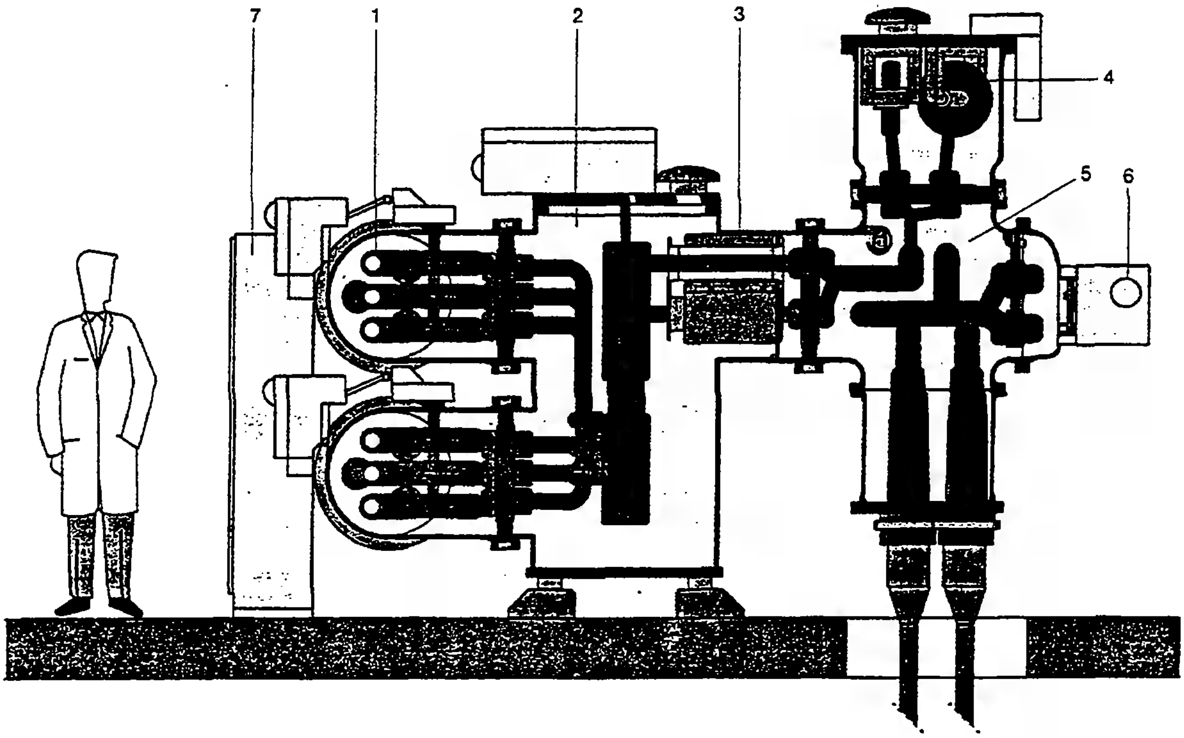
5.1.2 Schematic function of arc quenching mechanism of a circuit breaker pole



5.1.3 Metal-clad, SF6 Gas-Insulated Circuit Breaker



5.1.4 Cross section of double busbar cable feeder:



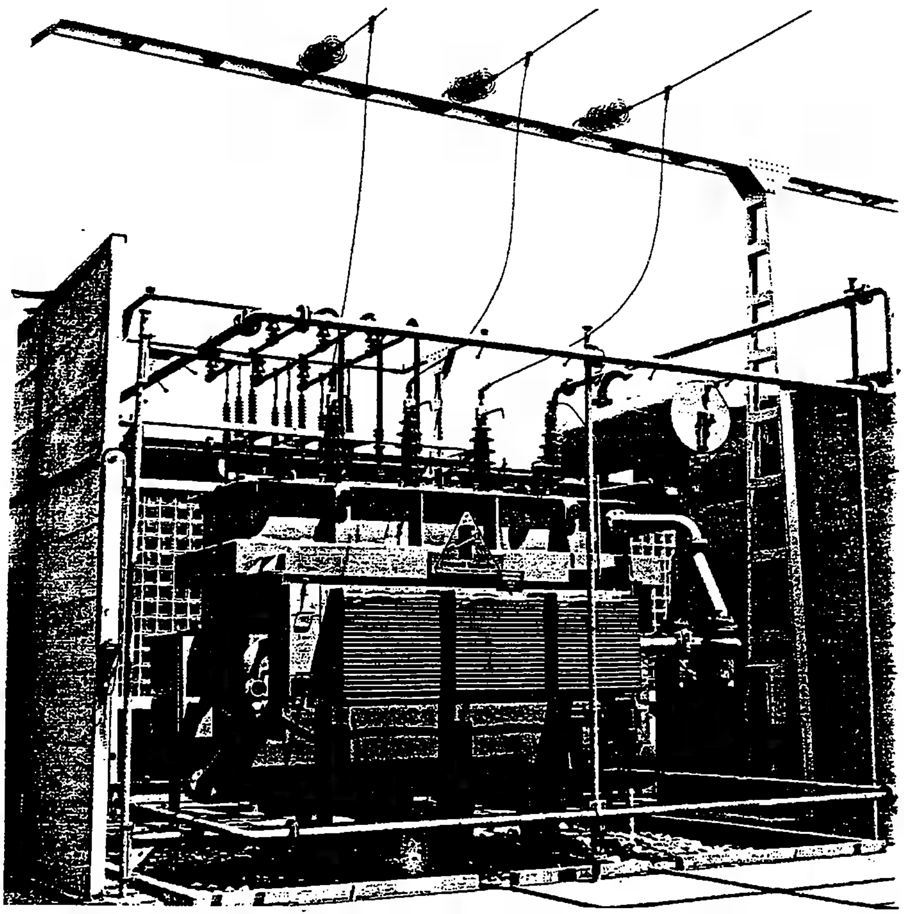
Legend

1	Busbar with combined disconnector/earthing switch
2	Circuit breaker
3	Current transformer
4	Potential transformer
5	Cable end unit with combined disconnector/earthing switch
6	Fast acting earthing switch
7	Control cubicle

5.2 High Voltage Transformer

Large high voltage transformers have an efficiency of up to 99%. They are always filled with oil which still copes best with all insulation and temperature problems. To meet the requirement for a constant voltage level in the cement factory under various loads and with varying voltage levels of the utility power supply, the transformers should be equipped with a tap switch which automatically increases or decreases the secondary voltage in steps of about 1 to 1.5%. Large transformer are equipped with air or water cooling equipment (a 20 MVA transformer with an efficiency of 98% still produces a flow of 400 kW of heat). Temperature sensors and the so-called 'Buchholz-Relay' protect the transformer against overload and insulation failures. The Buchholz-Relay detects gas bubbles which collect at the highest point of the transformer, and thus gives a good indication of insulation or local over temperature problems, in the transformer. The vector-group of a transformer is often Yd5, where 'Y' stands for primary star connection, 'd' for secondary delta connection, and '5' gives the phase relation between the two systems.

Figure 5.2 High voltage transformer



6. MEDIUM VOLTAGE EQUIPMENT

Medium voltage power distributions consist mainly of the same components as described in paragraph 5. They are generally of the indoor type. Today draw-out type cubicles are commonly used. Different equipment can be mounted on identical 'trucks'. The trucks are easy to handle and allow a quick replacement in case of a failure. The figure below shows a medium voltage distribution station.

Figure 6.0.1 Medium voltage substation

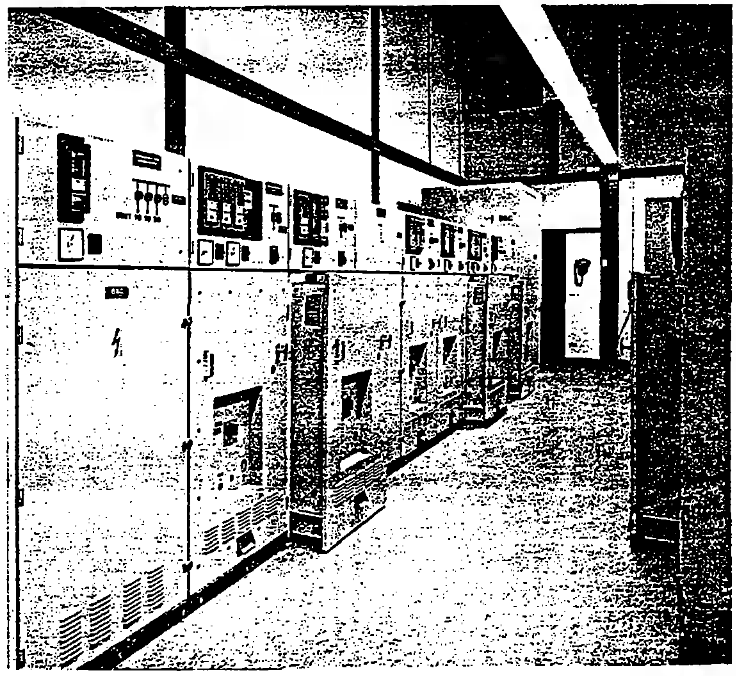
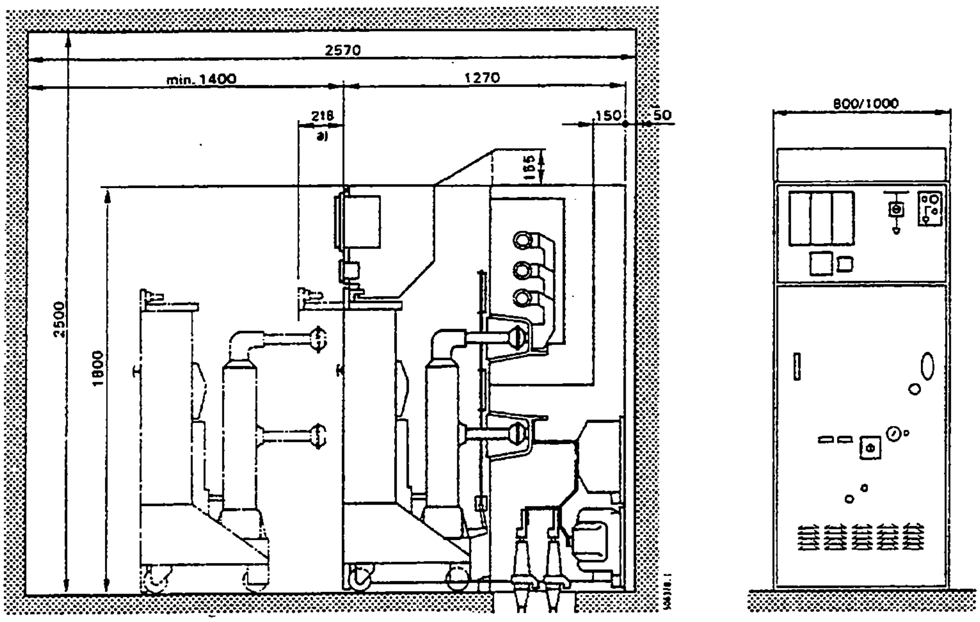


Figure 6.0.2 Typical arrangement with metal-clad SF_6 switch gear

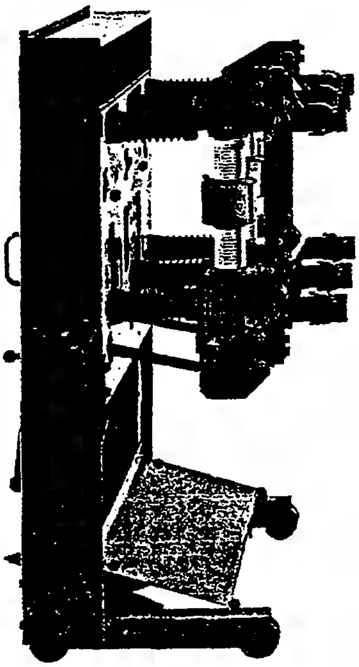


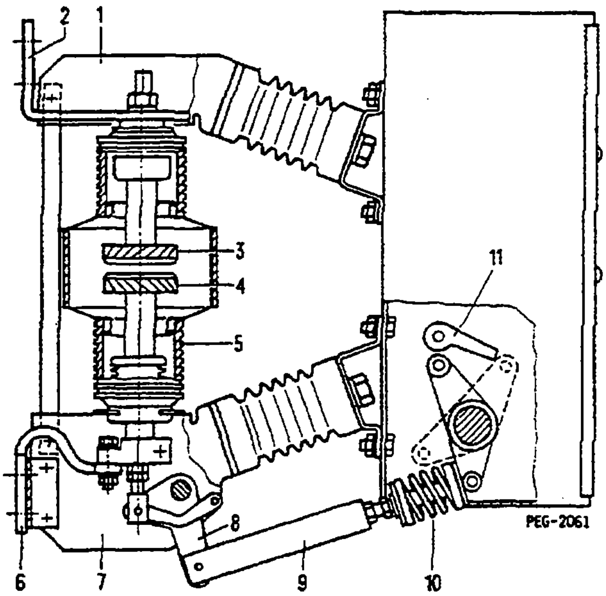
6.1 Medium Voltage Circuit Breakers

Vaccum- and SF_6 circuit breakers are normally installed in the medium voltage power distribution systems.

Low oil content circuit breakers are still manufactured but are less used due to higher equipment costs.

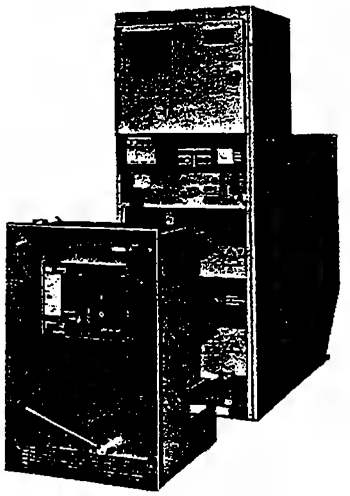
Figure 6.1.1 Truck mounted vacuum circuit breaker

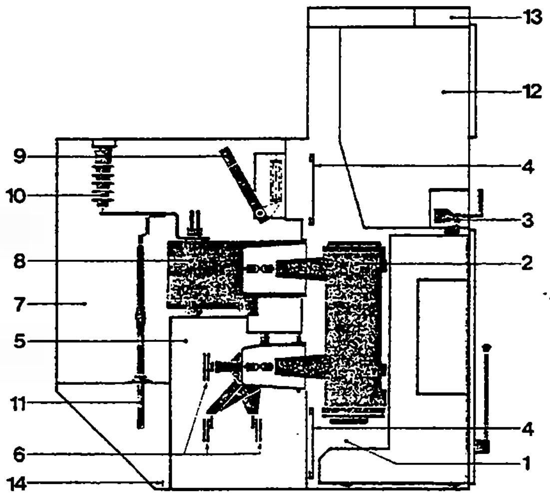




1 Upper interrupter support
2 Upper terminals
3 Fixed contact
4 Moving contact
5 Ceramic insulator
6 Lower terminal
7 Lower interrupter support
8 Angled lever
9 Insulated actuating rod
10 Contact pressure spring
11 Trip pawl

6.1.2 Truck mounted SF_6 circuit breaker





Legends
1 **Breaker compartment**
2 circuit break
3 LV plug-in connection between breaker and LV auxiliaries
4 metal safety shutters covering fixed disconnecting contacts
5 **Busbar compartment**
6 Busbars
7 **Cable-connection compartment**
8 Current transformers
9 Earthing switch
10 Potential dividers
11 HV solid-dielectric cables
12 **LV auxiliaries compartment**
13 LV wiring trough
14 **Earthing bus**

Properties of vacuum- and SF_6 circuit breakers

- **Application**:
  Protection and switching operation for
  - lines
  - cables
  - transformers
  - motors
  - capacitors
- **Criterias:**

	Vacuum	**SF_6**
Interrupter service life	20'000 to 30'000 C-0 operations	10'000 to 20'000 C-O operations
Service interval	Lubrication of mechanism(max. 10 years)	Lubrication of mechanism (max. 10 years)
Overhaul of interrupter	Interrupter to be replaced	Interrupter can be reconditioned
Switching of lines, cables, transformers, capacitors	Well suited	Well suited
Switching of motors	Well suited but measures may be necessary to limit over voltages	Well suited normally no measures necessary to limit over voltages

6.2 Medium Voltage Contactors

The psychical principles are similar to a circuit breaker, except that the contactor cannot interrupt short circuit currents. The contact system is optimised for high numbers of rated current operations.

High rupture capacity current limiting fuses in conjunction with the contactor are therefore required for the short circuit protection.

Overload protection is ensured by separate relays.

Fused contactors can be used as motor and transformer feeders.

Examples for max. fuse rating 250 A, 6 kV:

- distribution transformers max. 2000 kVA
- motor with max. starting current 1350 A and max. starting time 10 sec. - max. 1690 kW.

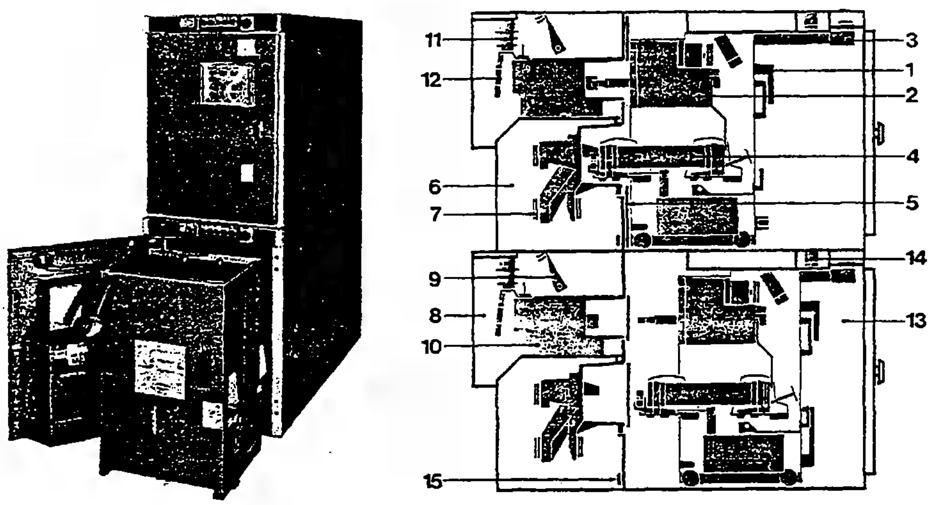
Advantages of fused contactors:

- very compact design
- more economical than circuit breakers

Disadvantages of fused contactors:

- tripping mechanism with auxiliary contact required for each fuse
- limited application (voltage, current)
- fuses to be replace

Figure 6.2 Contactor panel (double tier)

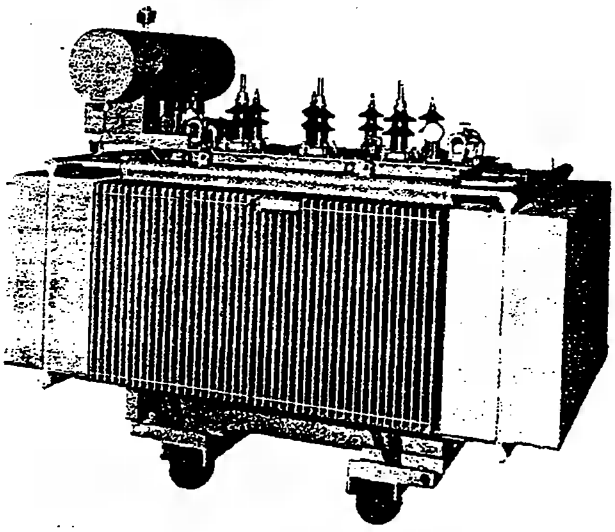


Legends
1 Fuse contactor compartment
2 contactor
3 LV plug-in connection
4 fuses
5 Metal safety shutters covering fixed disconnecting contacts
6 Busbar compartment
7 Busbars
8 Cable-connection compartment
9 Earthing switch
10 Current transforr
11 Potential dividers
12 HV solid-dielectric cables
13 LV auxillaries compartment
14 LV wiring trough
15 Earthing bus

6.3 Medium Voltage Transformers

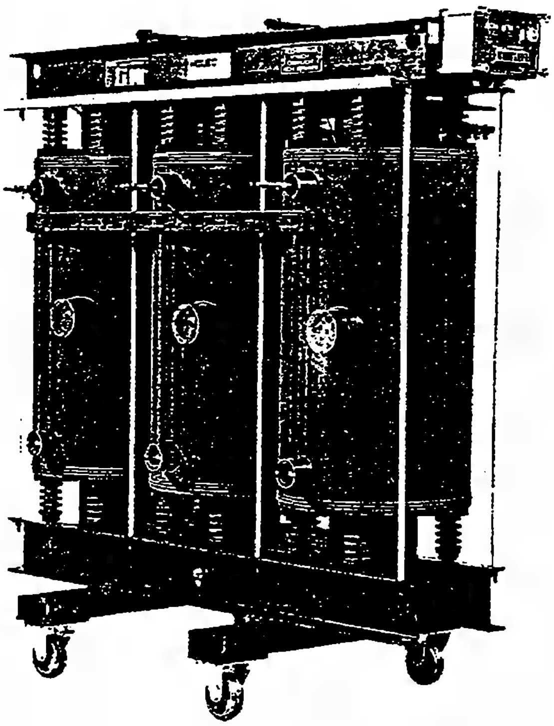
These transformers too are normally mineral oil-immersed. For special applications silicone oil is used which has less heat development during fire than mineral oil (10%).

Figure 6.3.1 Oil-immersed three-phase distribution transformer with oil conservator (hermetically sealed transformers without conservator are normally used up to 1000 kVA, resp. up to 20 kV)



So called 'dry' transformers which use a synthetic resign as insulation are built up to 10 MVA. They are more expensive than oil transformers.

Figure 6.3.2 Dry-type three-phase distribution transformer



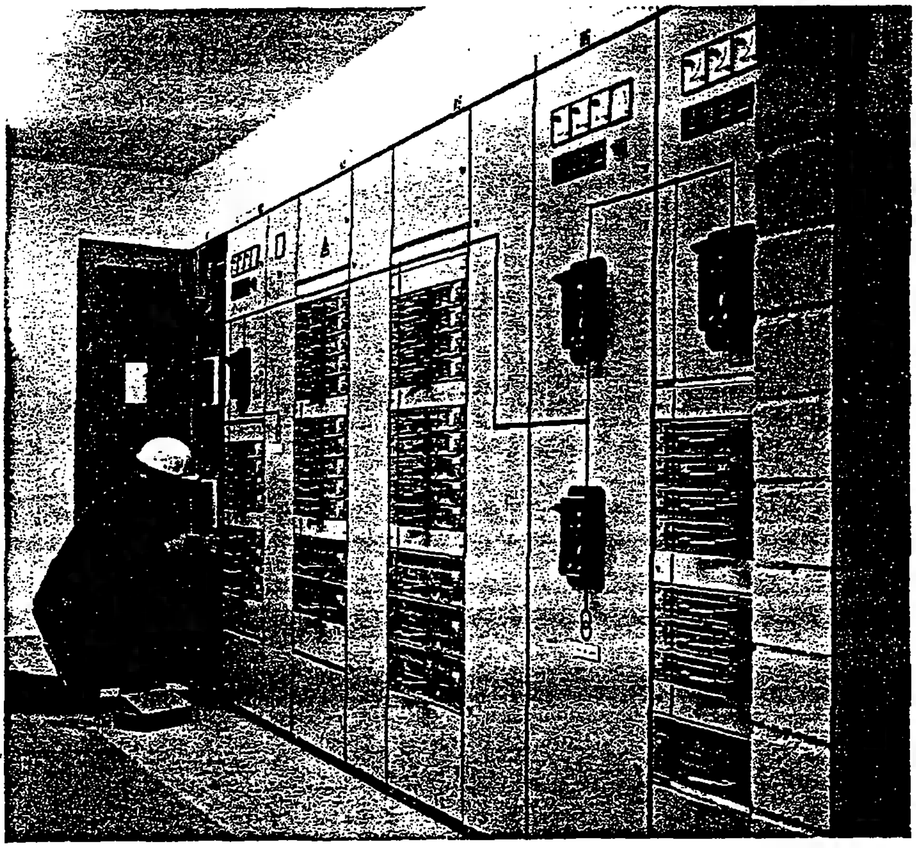
7. LOW VOLTAGE EQUIPMENT

Low voltage switch gear is located in electrical rooms in the different load centres of the plant.

7.1 Motor Control Centres

The motor control centres comprise all equipment for the remote control of the low voltage consumers (motors etc.). A fuseless and standardised execution of the feeder is preferred.

Figure 7.1 Motor control centre with outgoing feeders of the draw-out, fully-plugged design



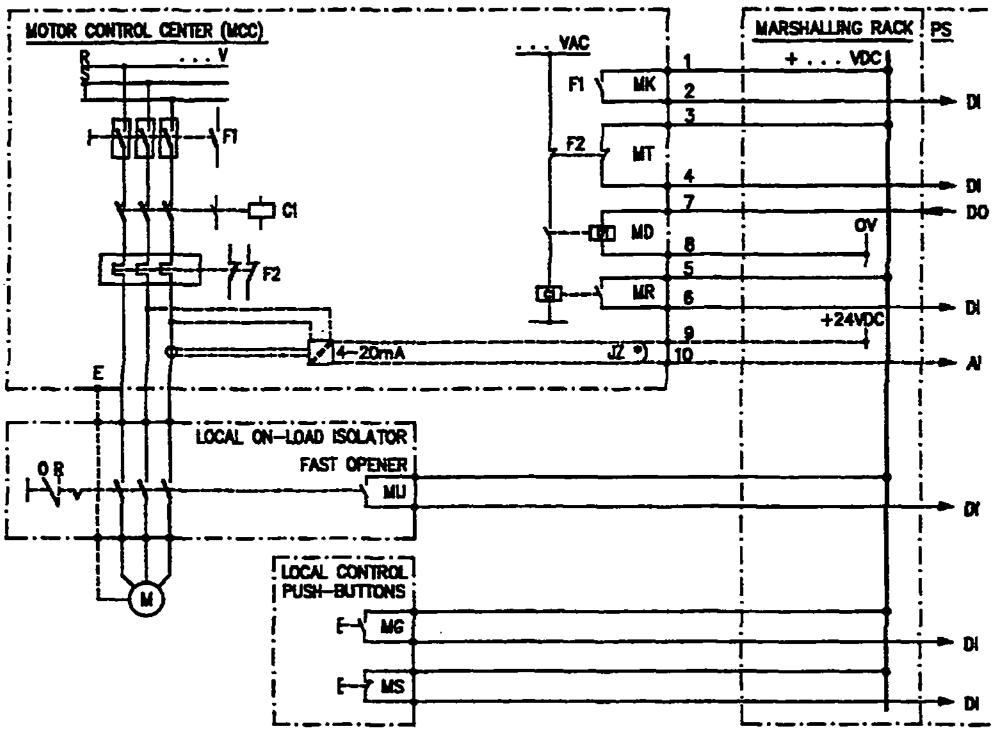
7.2 Motor Control Interface

The power- and control circuit wiring is normally standardised for each type of feeder.

For maintenance and repair purposes start/stop push buttons and OFF/READY isolator switches are located near each individual drive.

The DC-control circuits are connected via multi-core cables to the marshalling rack of the respective process stations.

Figure 7.2 Typical motor feeder circuit diagram



Legend:

MG.	Motor Local Go (Start)	DI:	Digital Input
MS:	Motor Local Stop	DO:	Digital Output
MU:	Motor Local Isolated	AI:	Analogue Input
MT:	Motor Thermal Overload	D1:	Interface Relay ... VDC
MR:	Motor Run	C1:	Contactor
MK:	Motor OK	F1:	Circuit Breaker
JZ:	Motor Power *) Option	F2:	Thermal Overload Device
MD:	Motor Start		

8. CABLES

The cable installation is an important part in a cement plant. The investment costs are in the range of 10 to 15% of the total costs for electrical equipment.

Types of cables

Power cables for

- High voltage (e.g. 110 kV) for incoming feeder from power company
- Medium voltage (e.g. 6 kV) for medium voltage power distribution of the plant
- Low voltage (e.g. 400 V) for low voltage power distribution of the plant

Control cables for

- Low voltage (e.g. 220 V) for control circuits
- Extra low voltage (e.g. 24 V=) for process control, instrumentation, communication.

Figure 8.1 Medium voltage power cable (3-core)

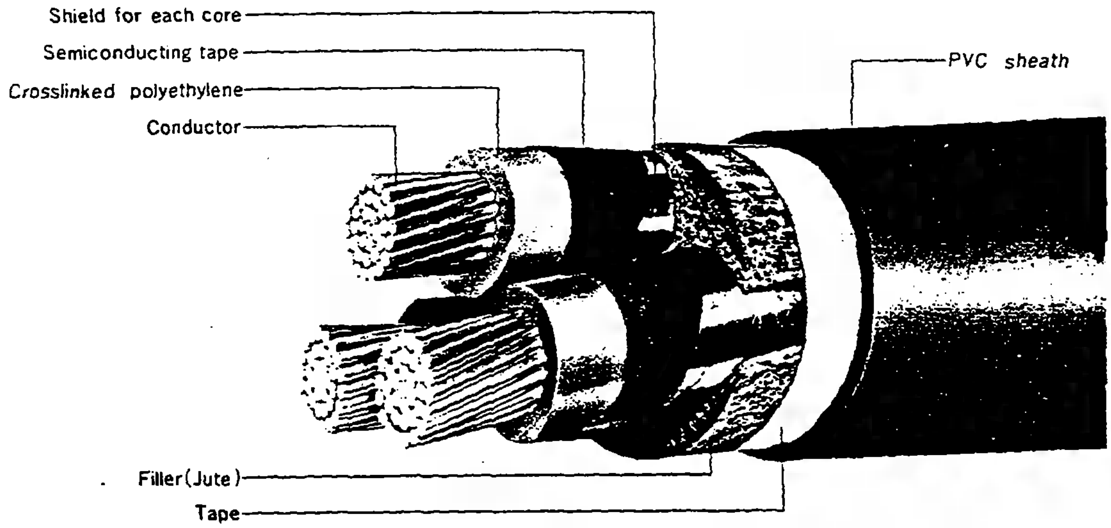


Figure 8.2 Low voltage power cable (4-core)

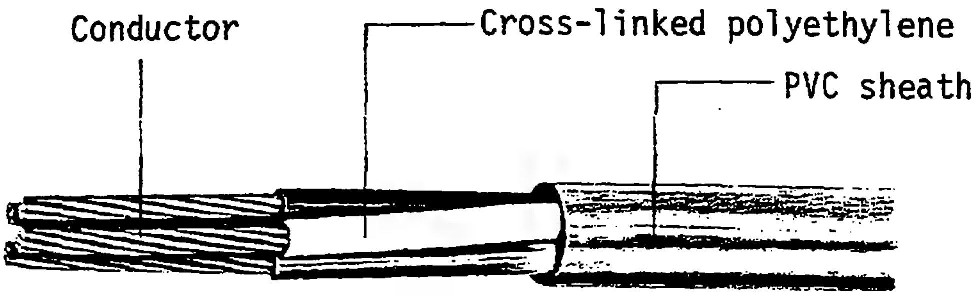
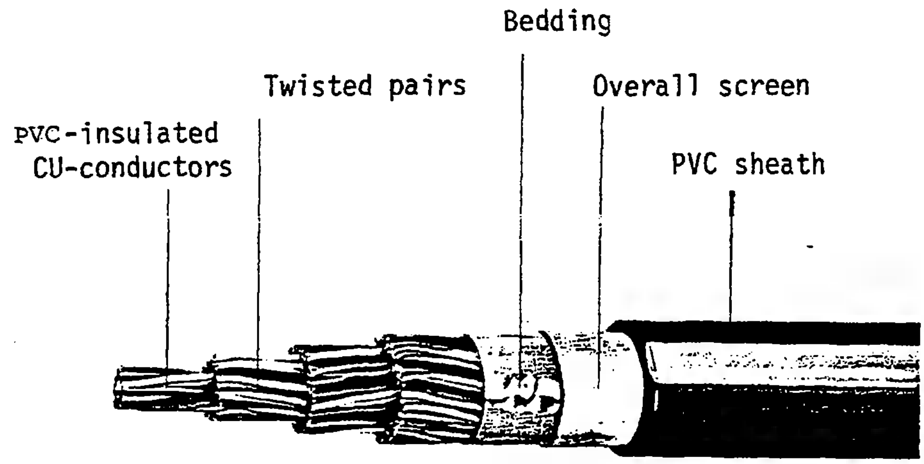


Figure 8.3 Extra low voltage cable (multi-core)



Polyethylene resp. cross-linked polyethylene (XLPE) insulated cables are the most widely installed power cables today in a cement plant. Ethylene-propylene-rubber (EPR) insulated cables will in future replace the PE resp. XLPE-cables.

Copper conductors are preferable to aluminium conductors due to the simpler installation method.

For special applications, cables with flame retardant, non-corrosive sheath material (EVA) can be installed.

Dimensioning of cables

Power cables have to be carefully dimensioned in respect of

- Current carrying capacity by taking into account
  - ambient temperature
  - kind of installation (ground, air grouping)
- Voltage drop (power loss)
- Thermal and dynamic short-circuits strength.

Installation of cables

In cement plants most of the cables are mounted on cable trays inside the buildings, on bridges, in walk-through cable tunnels or they are installed in pipe systems. Therefore, additional mechanical protection by armouring is generally not required.

9. POWER FACTOR AND ITS IMPROVEMENT

9.1 General

The induction motor is the largest producer of reactive power in a cement plant and shall be used here as an example.

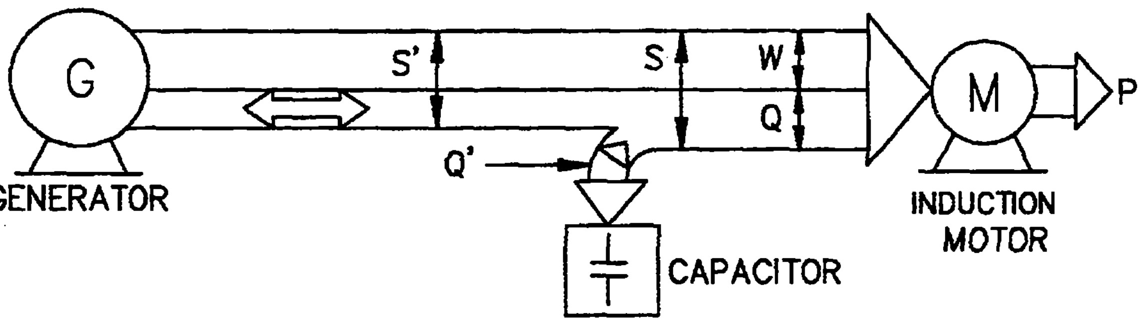
The induction motor draws two power components from the supplying network, or as shown below, from the generator, i.e.:

- the active power is transformed by the motor into mechanical energy
- the reactive power is transformed by the motor into magnetic energy; but with every change of polarity (with the frequency of the supplying network), the magnetic energy is transformed back to electrical energy.

in other words, it flows back and forth between the motor and the generator.

It can easily be seen that the reactive power is a burden on the generator and the supplying cables. It appears as a current like the active current and causes losses in the cables, transformers and in the generator.

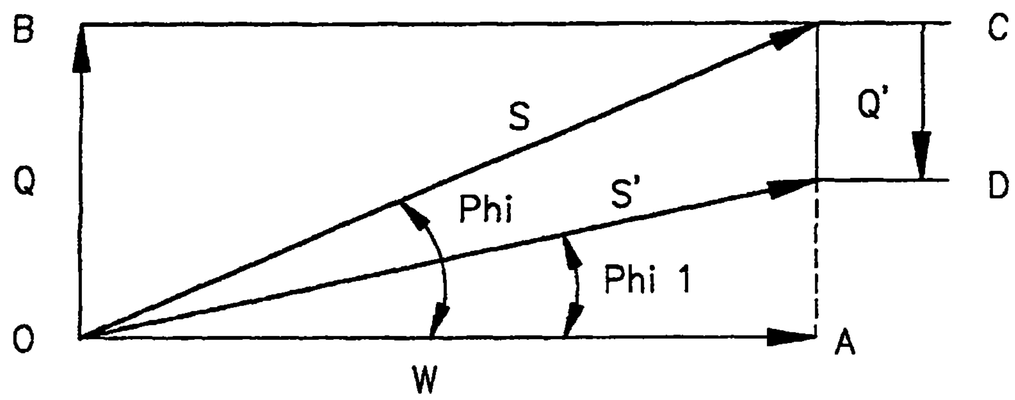
Figure 9.1.1 Typical power flow in motor circuit



Legend:

S:	apparent power	kVA
Q:	reactive power	kVar
W:	active power	kW
P:	mechanical power	kW

Figure 9.1.2 Vector diagram



Legend:

OA:	Active power W	(kW)
OB:	Inductive reactive power Q	(kVar)
OC:	Apparent power S	(kVA)
CD:	Capacitor reactive power Q	(kVar)
Phi:	Phase angle, uncompensated	
Phi_1	Phase angle, compensated	
Cos phi:	$\frac{W}{S}$	

The electricity authorities generally demand a minimum power factor (cos phi) to limit the losses in their own power distribution system.

One of the most common tools used to improve the power factor is the capacitor. A capacitor transforms reactive power into electrostatic power and back to reactive power with the frequency of the network.

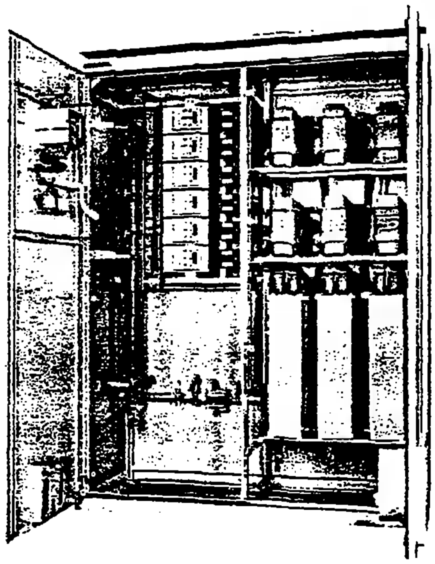
The capacitor can be compared with an expansion tank.

9.2 Power Factor Correction

The plant power factor is normally corrected in three different modes.

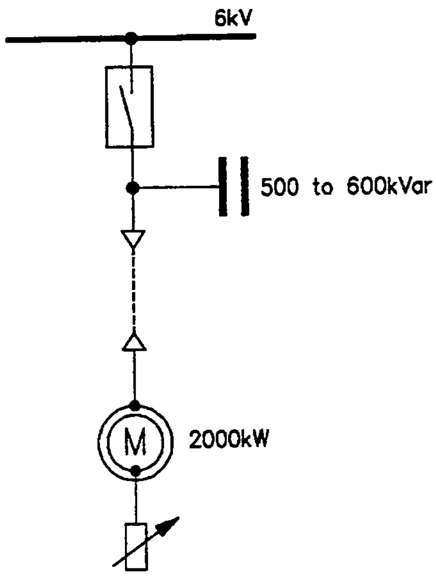
- For low voltage motors:
  They can be compensated through automatically regulated reactive current compensation plants situated at each low voltage power distribution.

Figure 9.2.1 Automatically controlled capacitor bank with line reactors (to cope with the harmonic content)



- For high voltage motors with constant speed:
  To correct the power factor, capacitor banks suitably sized for each individual high voltage motor can be connected and disconnected from the medium voltage power distribution with the respective motor circuit breaker.

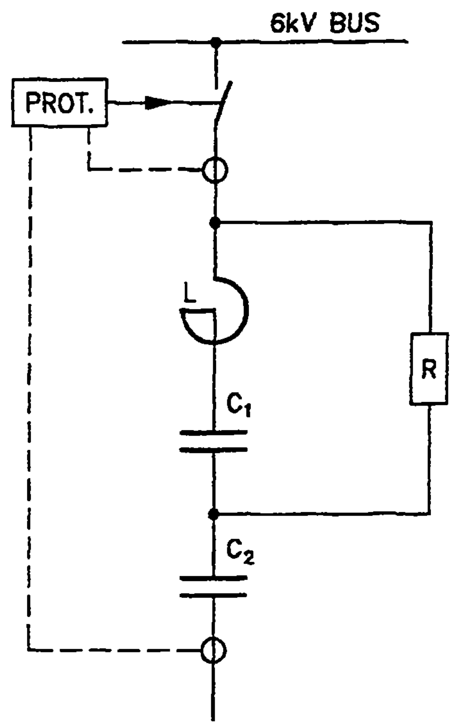
Figure 9.2.2 Direct compensated high voltage motor



- For large variable speed drives:
  It is recommended to compensate large variable speed drive systems through central reactive power compensation plants, correcting the power factor as well as higher harmonics generated by the various kinds of converters (one plant per medium voltage busbar section).

  Prior to the installation of a compensation plant, a detailed network analysis must be carried out.

Figure 9.2.3 Circuit diagram of a harmonic absorber and power factor compensation circuit (1 MVAr)



Legend:

L:	Inductance,	14.1 mH
R:	Resistor	50 Ω
C_1:	Capacitor	720 μF
C_2:	Capacitor	90 μF
PROT:	Protection	(MCX 912)

10. ENERGY- / POWER-METERING

The power distribution scheme of a cement plant shall comply with the process requirements. Independent process departments receive independent power supplies and distributions. Therefore, metering equipment shall be installed at:

- the H.V. incoming feeder (metering for energy invoice)
- the M.V. outgoing feeders to the individual process departments
- the M.V. outgoing motor feeders
- the L.V. outgoing non-process feeders
- the L.V. outgoing main motor feeders

This allows for detailed information such as:

10.1 Metering for energy invoice

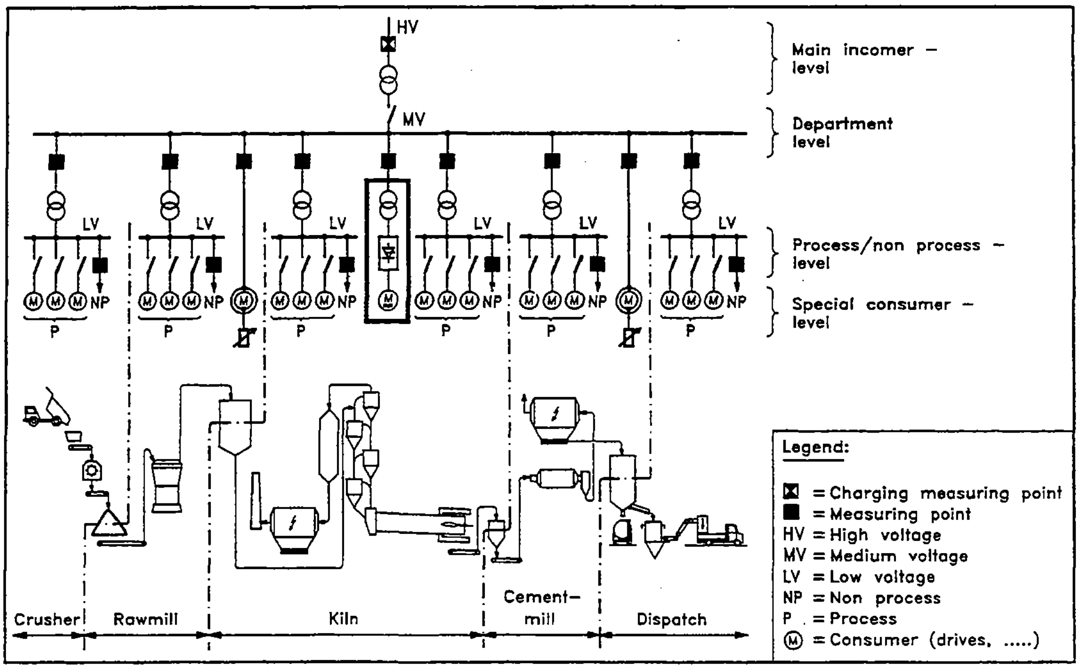
- total active energy consumption (kWh)
- total reactive energy consumption (kVarh)
- power factor (cos phi)
- total power demand (kW)

10.2 Metering for internal use only

- energy consumption per department (kWh)
- specific energy consumption per department (kWh/t)
- power demand per department (kW)

For a typical arrangement of metering equipment see Fig. 10.2.

Figure 10.2 Energy-/power metering in a cement plant



11. SAFETY PRECAUTIONS ON ELECTRICAL EQUIPMENT

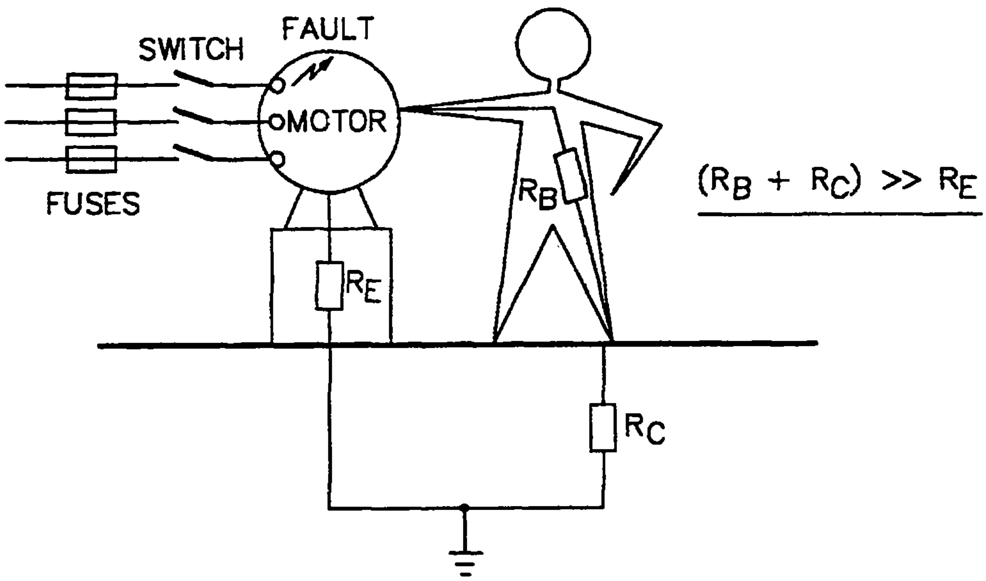
11.1 Introduction

The use of electrical equipment, from the main feed down to the hidden auxiliary servo-motor at the far end, spreads potential dangers all around the factory. The application of the safety precautions and regulations is the duty of all employees.

All electrical systems are grounded to earth to reduce the shock hazard to personnel and to provide a path to ground for currents induced in the system by lightning strokes.

11.2 'Touch' Voltage

Figure 11.2 Equivalent circuit of a person exposed to 'touch' voltage



Touch voltage is defined as the potential difference between a grounded point and a point on the earth's surface equal to a person's normal maximum horizontal reach. Fault current flowing into the earth via the grounded casing of the motor will develop a voltage drop across R_E, representing total ground system resistance. A person touching the faulty motor will be safe as long as his body resistance R_B and his contact resistance to the earth R_C are much bigger than R_E. The body resistance R_B varies greatly, even on the same person, between approx. 1,300 Ohm on a hot day in a humid atmosphere and approx. 3,000 Ohm in dry weather and with dry hands.

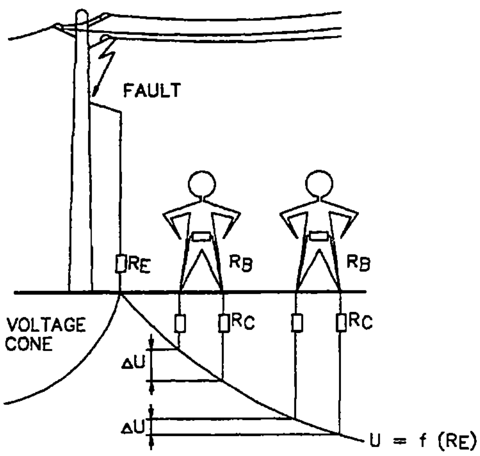
The maximum permissible voltage the body can be exposed to without immediate danger is 65 V. This corresponds under worst conditions to a maximum current of:

$$\frac{65}{1300} = 0.05\,\text{A}$$

These values of 65 V and 0.05 A are laid down in the German VDE regulations. In many countries, however, the voltage considered to be safe is 50 V.

11.3 'Step' Voltage

Figure 11.3 Equivalent circuit of a person exposed to 'step' voltage



'Step' voltage is another hazardous condition caused by distributed voltage gradients. It is defined as the potential difference between two points on the earth's surface separated by a distance of a person's pace (about 1 m). The figure above illustrates such a condition. Again, fault current flowing into the earth via the grounded pylon will develop a voltage drop across R_E representing the total ground system resistance. Voltage appearing across portion ΔU will determine the magnitude to which the body will be exposed. Keeping the total ground system resistance low will reduce the value of Δ U for safety purposes.

11.4 Safety Precautions in High Voltage Equipment Rooms

The electrical equipment in the plant has to be protected in such a way that no one can touch any live parts. National as well as international safety codes have set up strict rules for all equipment, its insulation, wiring and earthing.

In electrical rooms, strictly accessible to trained electricians only, different regulations apply which allow for live parts to be exposed.

Special precautions therefore have to be taken in case of alterations and/or maintenance in such rooms. Under no circumstances should artisans of other trades (e.g. masons) be allowed to work in such rooms without the supervisions of an electrician. Temporary barricades may also be required to isolate work areas to prevent accidental contact with energised high voltage parts.

11.5 Preventive Maintenance

Each cement plant has a variety of mobile equipment which is temporarily connected to the power or light network by means of cord connections. Such flexible connections are subjected to abnormal wear; the electrical staff must, there- fore, pay special attention to proper maintenance and repair.

The grounding system has to be measured at regular intervals to assure its low resistance and to detect any faulty or corroded connections.

It is recommended to protect all plug sockets by differential current earth leakage breakers.

In areas where flammable or potentially explosive goods are stored or handled, the electrical installations have to be flame-proof or explosion-proof. Such equipment may be necessary within sections of the oil treatment plant or near natural gas installations.

11.6 Precautions against Electric Fires

An American factory insurance company has compiled statistics showing that wiring alone is responsible for almost half the electric fires, and that over half the losses could have been avoided by correcting minor wiring defects.

Sufficient attention is normally paid to the proper protection of oil filled transformers, thus limiting damage because of fire.

Wiring, however, covers large areas of every structure; it is attached to or part of all types of machinery, and is exposed to almost every conceivable environment; heat, cold, dust, moisture, oil, vibration, corrosive liquids and gases. Cables are grouped in large steel enclosures, floor trenches, junction boxes, pits, manholes, and tunnels. Fires in such places are often well-advanced before being discovered. The limited accessibility impedes the application of extinguishing agents.

The almost universal use of PVC-covered and sheathed cables can increase the damage of such fires because of the extensive development of fumes of hydrochloric gases which combine to hydrochloric acid in the presence of moisture.

As a protection against such damages and prevention of plant interruption caused by wiring fires, the following means should be considered:

- installation of sprinklers
- division of long cable tunnels or trenches into partitions
- proper insulation of hot stream or oil pipes using the same tunnel
- proper protection against sparks during welding operations
- sufficient separation and ventilation of cables subjected to high loads
- marking of escape routes in trenches

11.7 Maintenance of Temporary Installations during Construction and Erection

Special attention has to be paid to the proper handling and maintenance of temporary installations. Cables suspended on steel structures are dangerous; if they tear they can set alive the whole structure. Mobile boom cranes, which can quickly change their working location, are frequently the cause of electrical accidents when they touch overhead lines or tear down suspended cables.

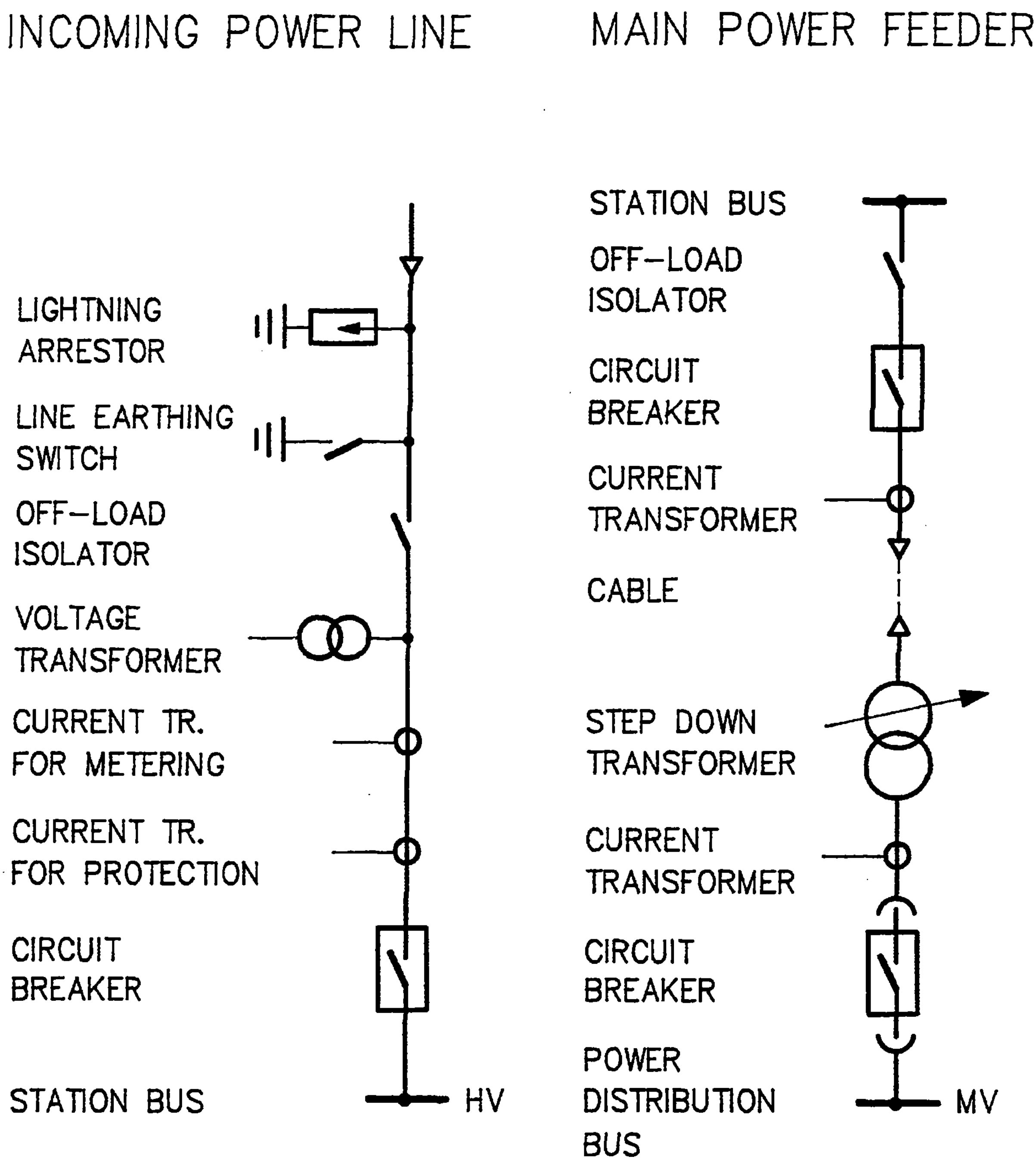
11.8 First Aid

First aid instruction posters are commonly available and prescribed in electrical rooms.

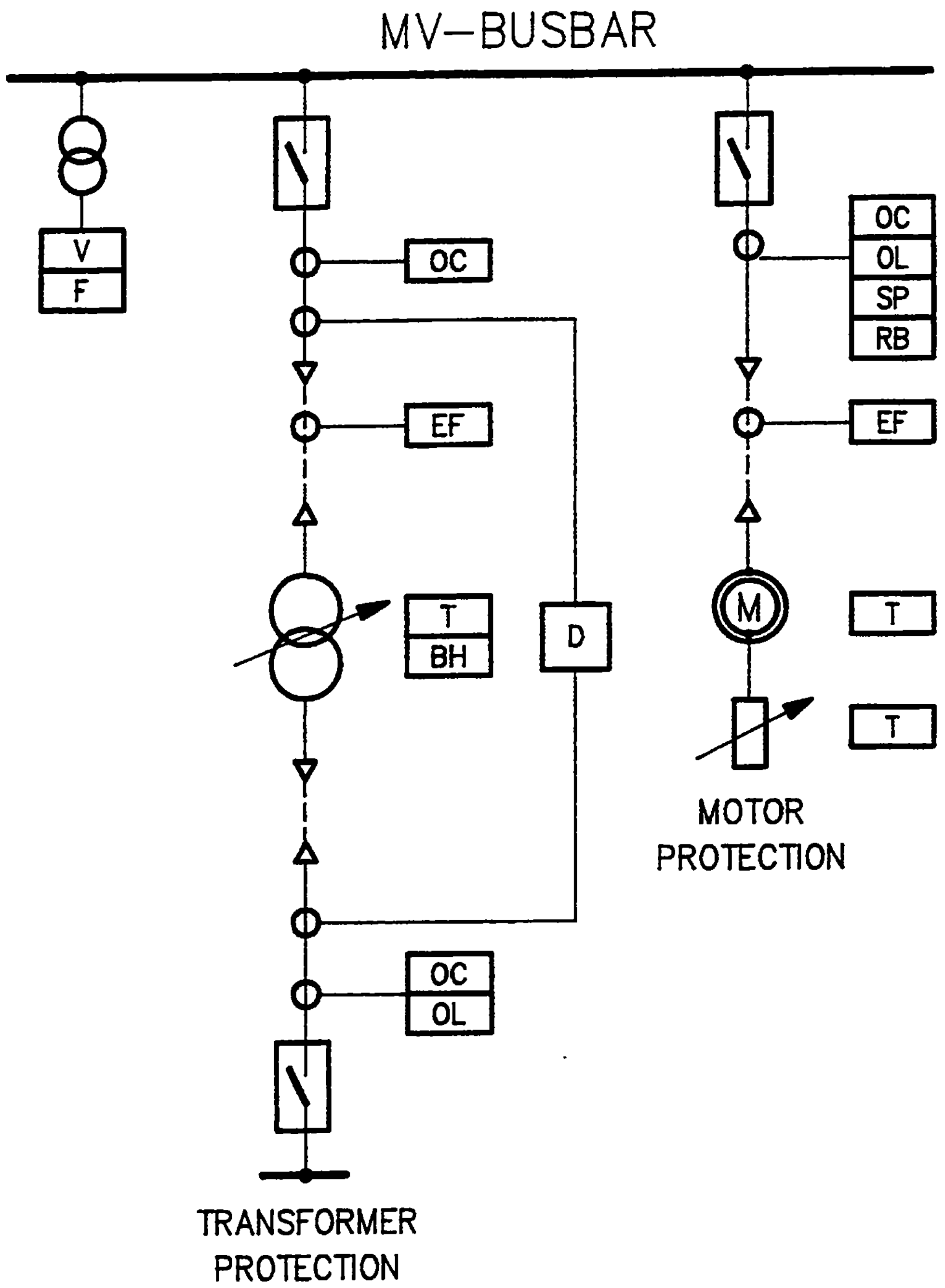
Since quick and correct action in case of an electrical accident is of vital importance, first aid training should take place at regular intervals.

12. ANNEXES

12.1 Power Supply
Typical elements of a high voltage transformer station



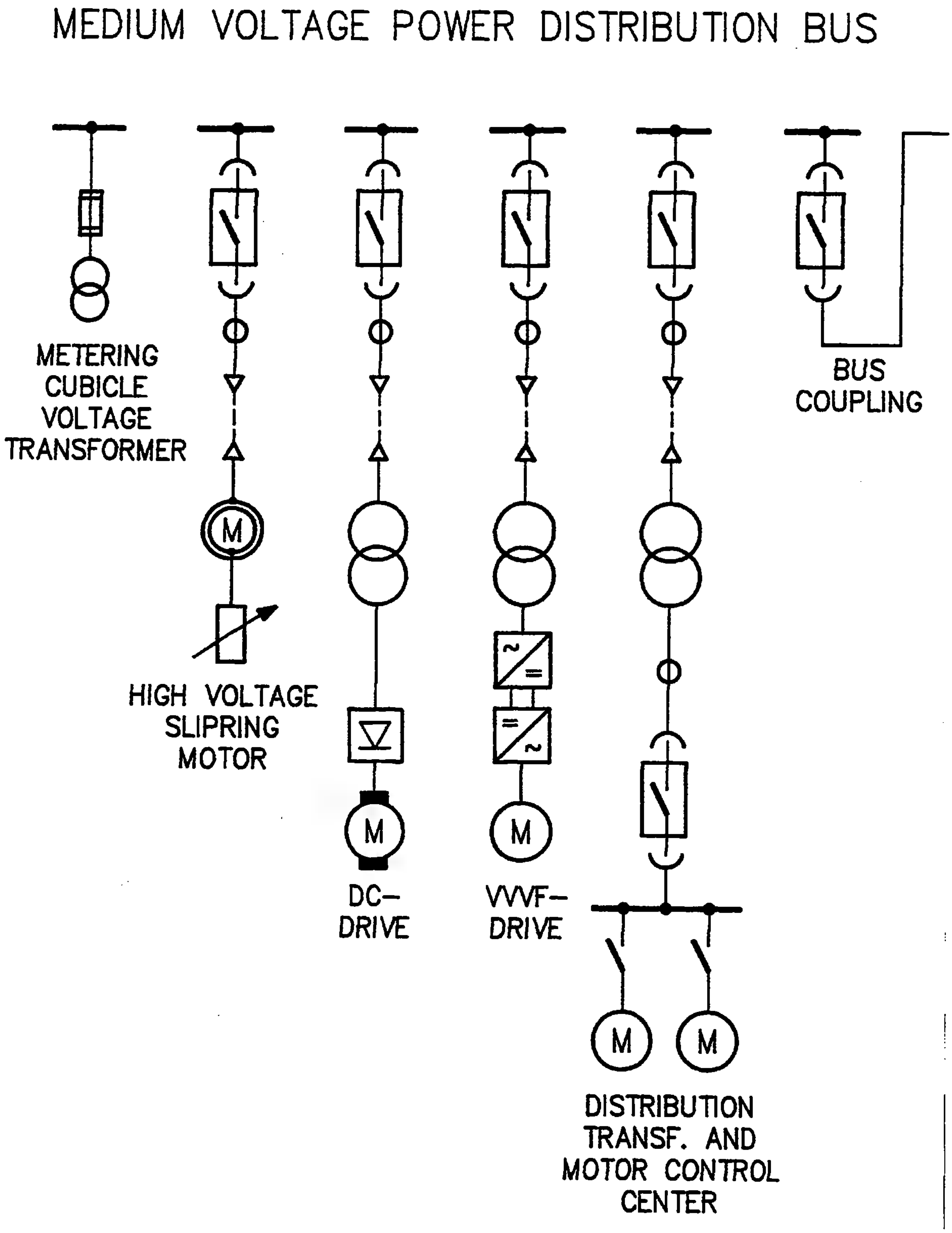
12.2 Power Distribution
Protective relays



LEGEND:

V	VOLTAGE	RB	ROTOR BLOCKAGE
F	FREQUENCY	EF	EARTH FAULT
OC	OVERCURRENT	D	DIFFERENTIAL PROTECTION
OL	OVERLOAD	T	TEMPERATURE
SP	SINGLE PHASE	BH	BUCHHOLZ

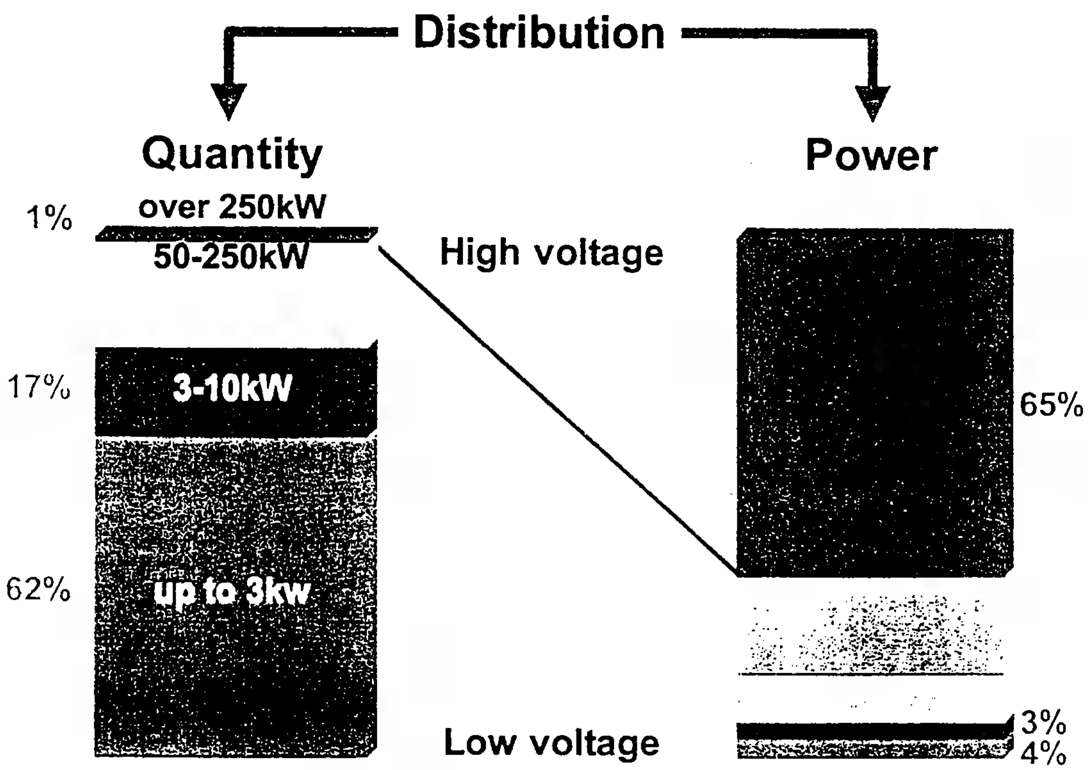
12.3 Power Distribution
Typical elements of a medium voltage power distribution



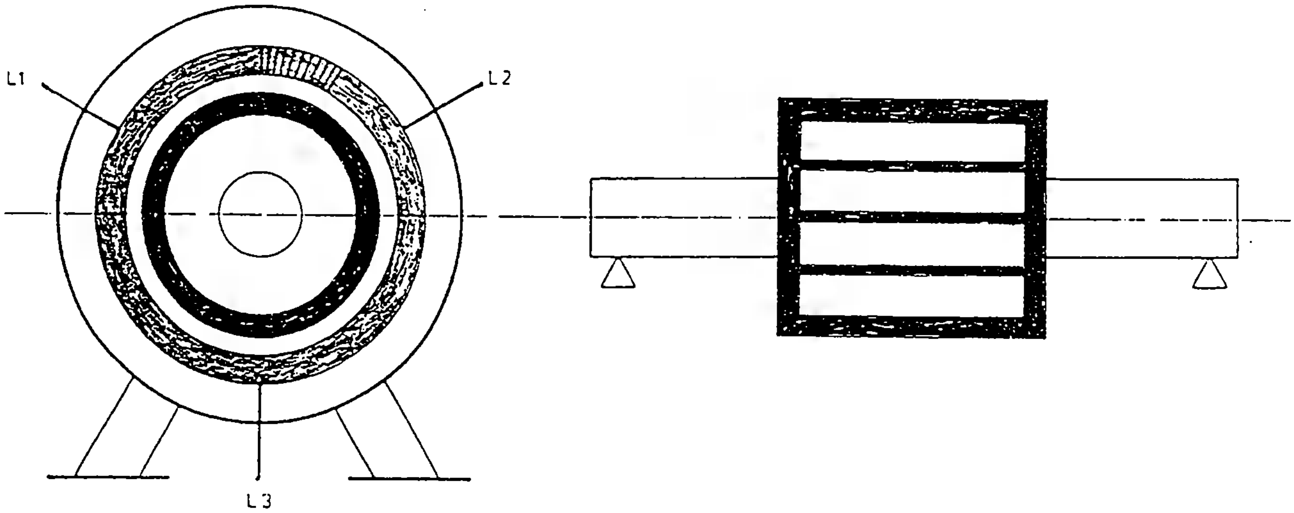
Motors and Drive Systems

1.) Types of motors
2.) Protection forms of motors and cooling
3.) Characteristics of motors (torque)
4.) Maintenance aspects
5.) Variable speed drive systems (mechanical / electrical)
6.) Drive system efficiency

Electrical Drives



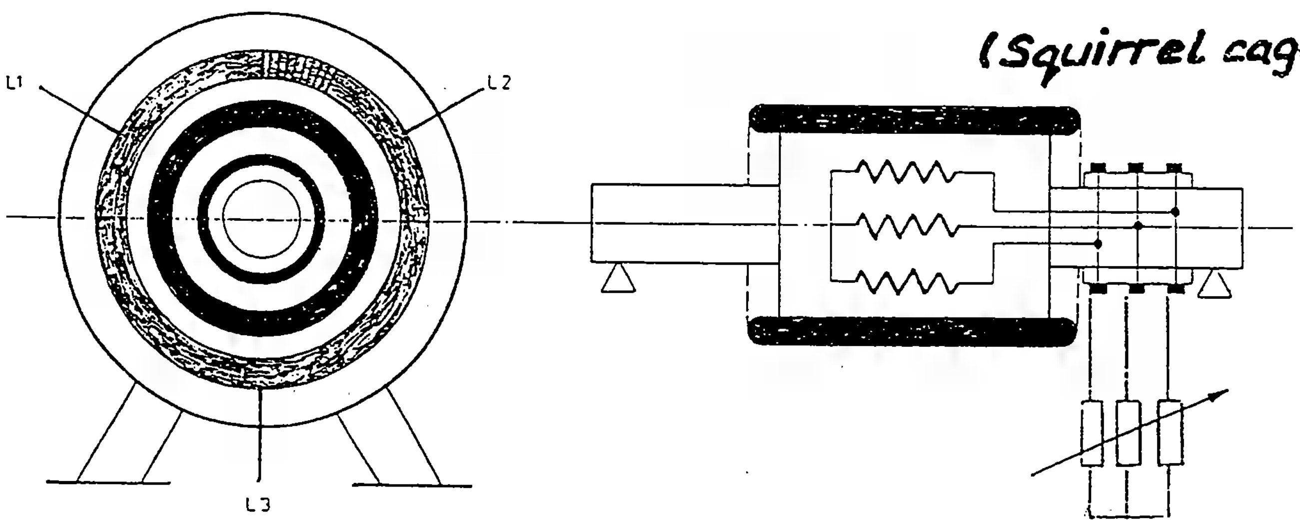
SQUIRREL CAGE MOTOR



SLIPRING : STARTING ONLY

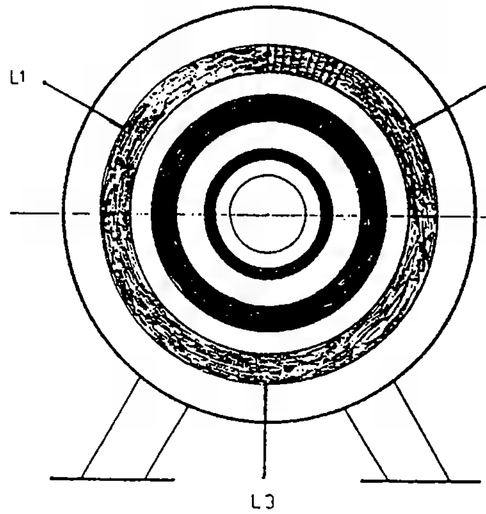
OPERATION : SHORT CIRCUIT (Squirrel cage)

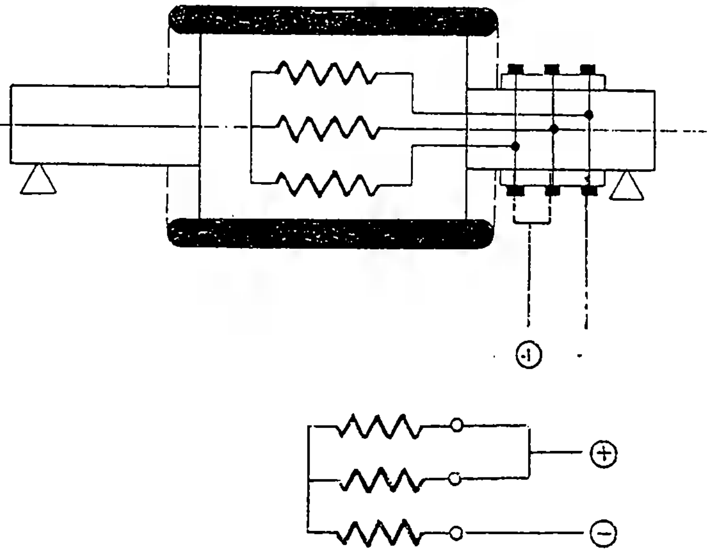
SLIPRING MOTOR
(WOUND ROTOR)



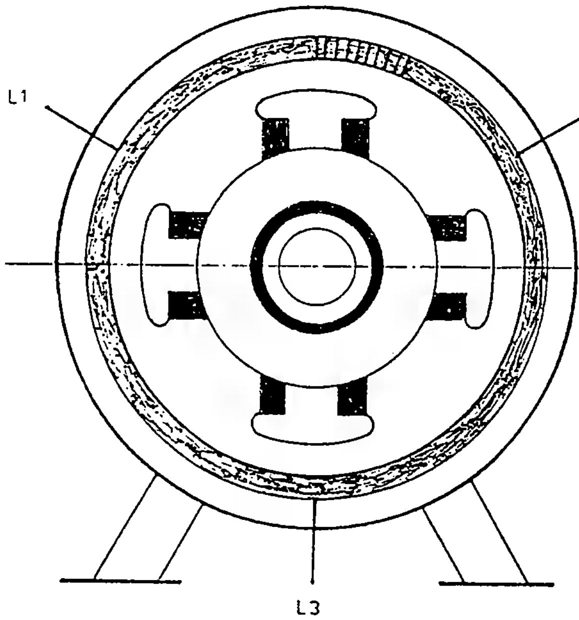
SLIPRING MOTOR
(WOUND ROTOR)

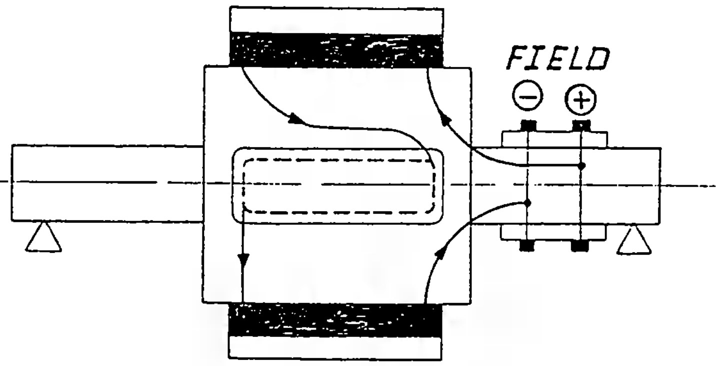
SYNCH. INDUCTION



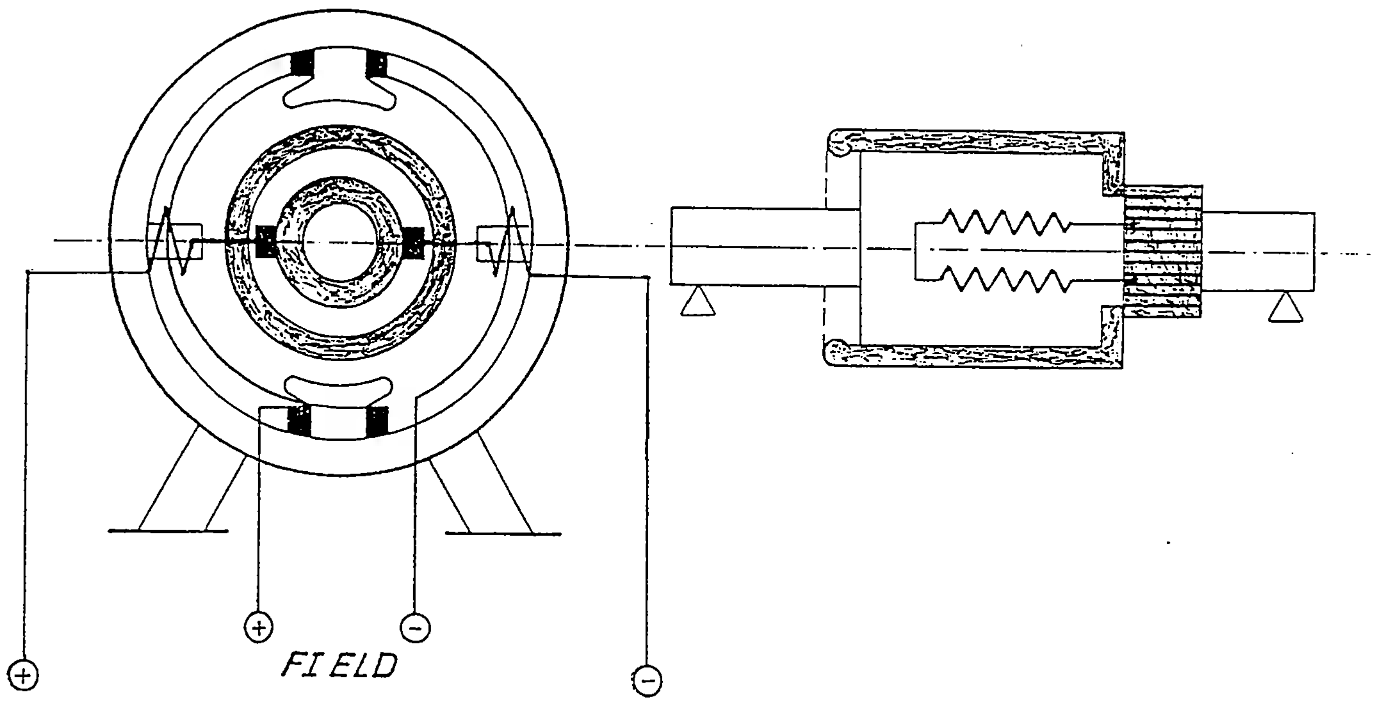


SYNCHRONOUS MOTOR





DC - MOTOR



Motors / Drives "Cement Seminar 2000"

- Motors > 250 - 300kW → MV-motors (i.e. 6kV, 3kV)
- Motors < 250kW → LV-motors (i.e. 400V, 500V)

Two types of motors:

→ Constant speed motors
→ Variable speed motors

Motors / Drives "Cement Seminar 2000"

Constant speed motors → AC squirrel cage motor (most common drive in cement plant)

- To be considered:
  - Inrush current (5-7 times full load current)
  - Starting time → voltage drop on power distribution (< 10-15%)

↓ If problem

→ Slipping motor with rotor starter

Motors / Drives "Cement Seminar 2000"

Constant speed motors → AC synchronous motor (very seldom in cement plant)

- To be considered:
  - low starting torque
  - May be used for power factor compensation
  - Mostly used with converters

Motors / Drives **"Cement Seminar 2000"**

Variable speed motors:

→ AC-slipring motor with variable resistor or slip-recovery system for i.e. large fans
Note: speed depends of the load

→ DC-motor with thyristor converter for i.e. kiln drive
Note: speed is independent of the load

→ AC-squirrel cage motor with static frequency converter control for i.e. fans
Note: speed is independent of the load

$$\text{synchronous speed} = \frac{\text{frequency} \times 60}{\text{no of poles on motor}} \text{ (rpm)}$$

Motors / Drives **"Cement Seminar 2000"**

Maintenance methods:

- Preventive maintenance based on vibration measurement
- Preventive maintenance based on thermography
- Preventive maintenance based on periodical inspection
- Corrective maintenance based on break-down

Motors / Drives **"Cement Seminar 2000"**

Motors with brushes:

→ Most maintenance demanding equipment → carbon dust
- Quality of the sliding contact dependent on atmosphere (humidity)
- Current density commutation (current density is directly proportional to temperature) → leading to evaporation of the moisture in the air

→ Patina or commutator skin

- Normal brush wear: ca. 3-5mm per 1000 hours; to be frequently measured / recorded

Motors / Drives "Cement Seminar 2000"

Brush wear:

➔ Carbon dust has to be removed because conducts electricity; to be cleaned:
- ➔ By vacuum cleaner
- ➔ Slipring hub and brush assembly to be cleaned with a rag

⚠ Job to be done several times per month, depending on running hours

➔ Brush has to move freely in brush holder
- ➔ If not: increased brush wear and sparks will be created

➔ Uneven sliprings have to be polished or skimmed off on a lathe

➔ Commutator / slipring housing to be painted white: carbon dust, easily noticeable

06.05.99 / 7

Motors / Drives "Cement Seminar 2000"

Reason for sparks leading to excessive brush wear:

- Stuck brushes
- Stuck pressure finger
- Worn brushes
- Oil on contact surface
- Scratched contact surface
- Vibrations (max. 2-3 mm/sec.)
- Brush position (adjustment)
- Dust (abrasive dust)
- Carbon brush quality
- Too good contact → increased current → sparking due to overload
- Equipped with thyristor converter: break down of thyristor, diode fault in supply circuit, fault in control equipment or a fuse

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Motors / Drives "Cement Seminar 2000"

One can distinguish between 4 colors of sparks on the commutator:

① Small violet sparks are almost harmless.

② Red sparks arise with overload and result in brush wear.

③ Blue sparks, shining with glowing particles, usually indicate inferior communtation. Both brushes and commutator will be damaged.

④ Green sparks, always together with glowing particles, indicate serious defects, causing rapid destruction of brushes and commutator.

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Motors / Drives "Cement Seminar 2000"

Rotor-starters:

- To be checked on regular intervals
  - → Contact tips to be visually inspected
  - → Check insulation oil (can be regenerated)
  - → Monitor temperature of oil-cooled or liquid filled starters
  - → Liquid filled starters: level and concentration of electrolyte to be monitored

06.05.99 / 10

Motors / Drives "Cement Seminar 2000"

Testing insulation resistance on motor windings:

- To be done for new motors, long idle period, newly rewounded motors
  - →LV-motors: 500V-megger
  - →MV-motors: 1[st]: 500V-megger, if o.k.
    2[nd]: 1000-2500V-megger

$$\text{measured insulation resistance} > \frac{20 \times \text{operating voltage (V)}}{1000 \times 2 \times \text{output power (kW)}} = M\Omega$$

(Formula valid for 25°C, 500V-megger: one minute; if temperature is not to be corrected)

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Motors / Drives "Cement Seminar 2000"

Condition monitoring of motor / drive system:

- Thermography (see chapter power distribution)
  - → Used for motor / terminal box / frequency converter panels
- Vibration control
  - → Shock pulse meter to check operating condition of ball and roller bearings
  - → Used for preventive maintenance and long-term planning

Low shock valve:	good condition
High shock valve:	sign bearing faults, bad installation, insufficient lubrication

- Cooling air installation for motors
  - → Filters to be cleaned
  - → Check if sufficient cooling air is available

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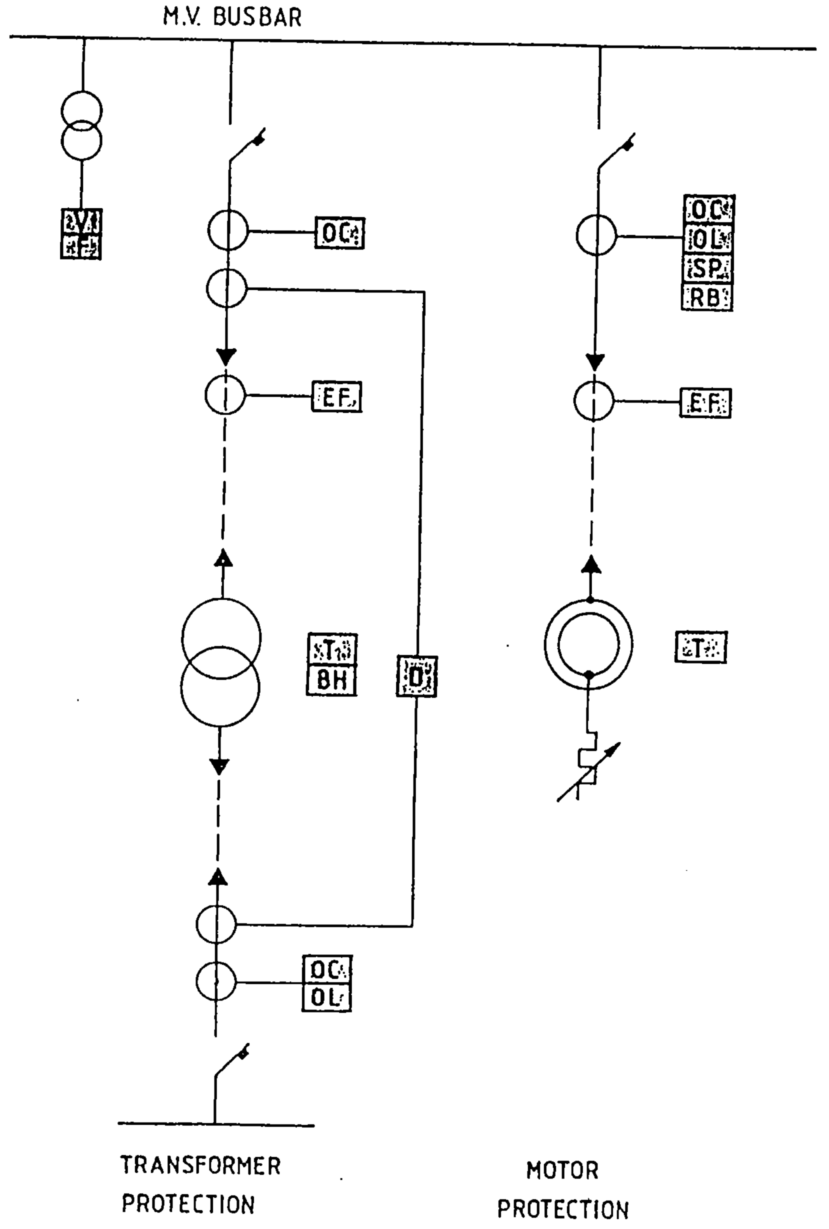
Motors / Drives **"Cement Seminar 2000"**

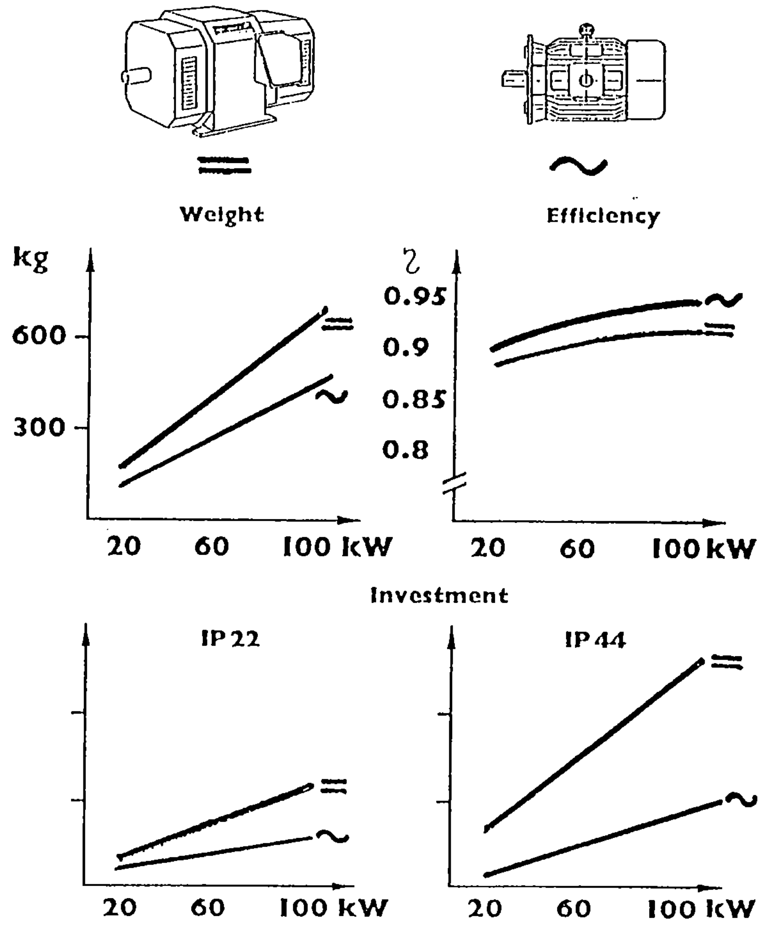
Motor protection:

- Today's standard are multiple microprocessor based protection relays
  Following faults / conditions are detected
  - *Thermal overload*
  - *Time / current characteristics*
  - *Start-up supervision*
  - *High-set over current*
  - *Incorrect phase sequence*
  - *Under current*
  - *Cumulative start-up time counter*
  - *Self-supervision*
- Motors > 100kW requires thermal sensing / protection device for:
  - *Stator*
  - *Winding (resistance thermometers, thermistors; semiconductor temperature sensor)*
    → cannot be replaced
  - *Sleeve / roller bearings (contact or resistance thermometers)*

PROTECTIVE RELAYS



Comparison DC/AC Motor

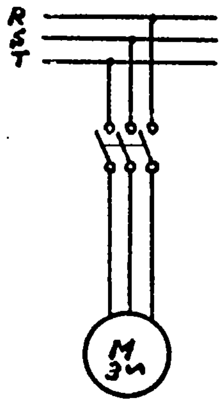


Additional benefits of the AC-Motor
- Higher reliability
- Virtually maintenance-free

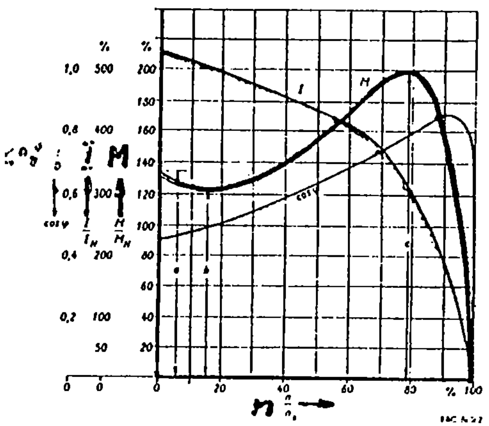
b) SQUIRREL CAGE MOTOR (INDUCTION MOTOR)

Construction

- The squirrel cage motor is in its construction the simplest motor used in the cement industrie
- The main feature is a rotor without external connections (no slip rings, no brushes)
- Its two bearings are the only parts exposed to wear and tear.
- It is economical in price

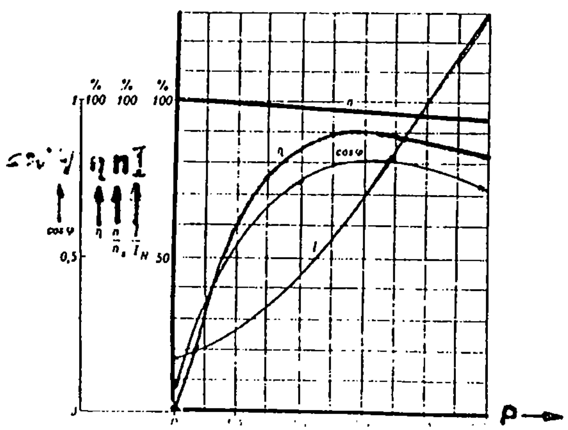


TYPICAL STARTING CHARACTERISTIC



a Starting torque
b Sattle "
c Break down "
i Current
m Torque
n· Speed
cosφ Power factor
η Efficiency
p Load

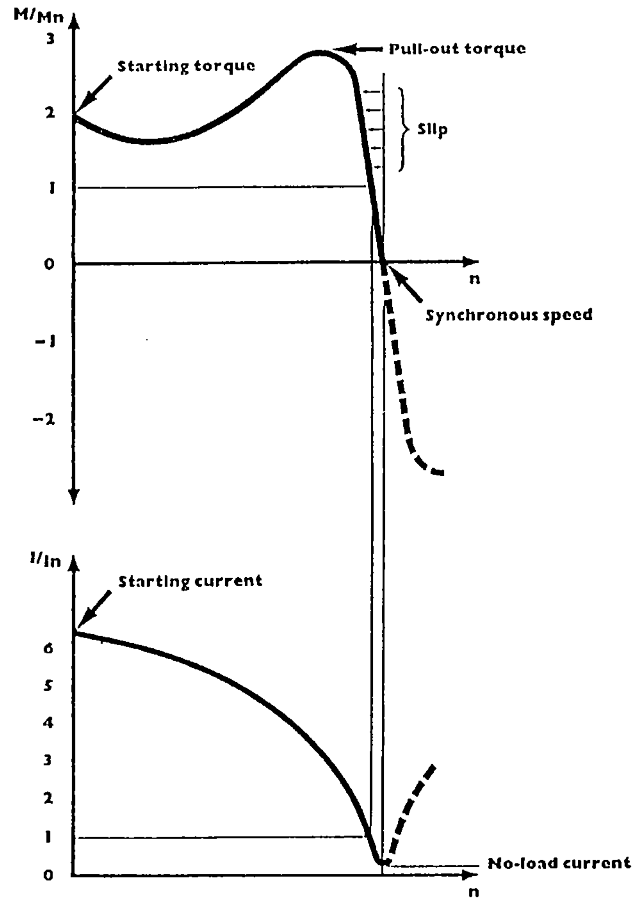
OPERATING CHARACTERISTIC

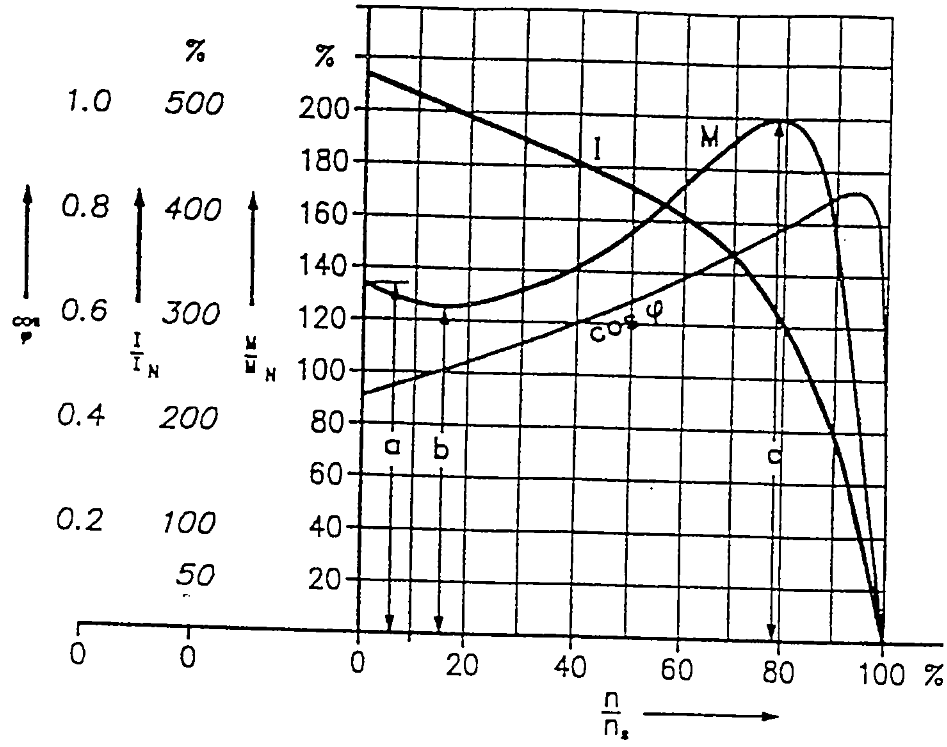


PROPERITIES :

- High starting current 3,5 to 7 times full load
- Relatively constant speed
- Torque changes with the square of the voltage

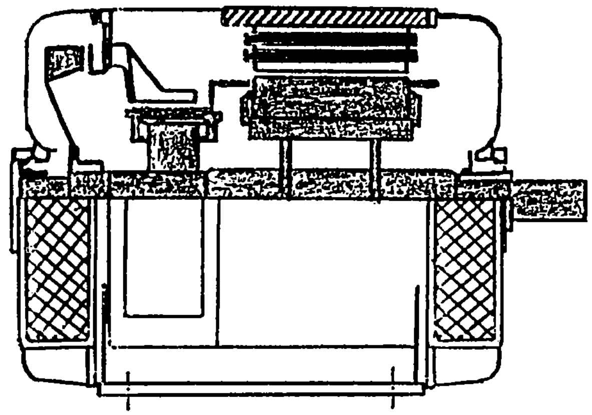
Torque Curves

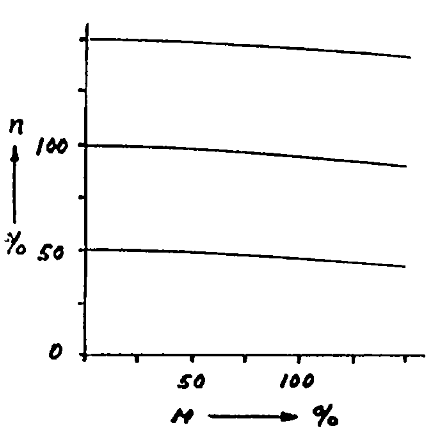


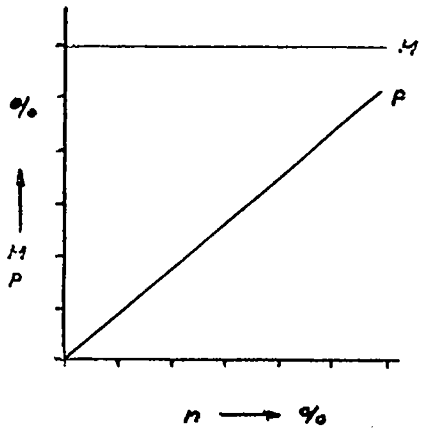


a : starting torque
c : break-down torque
M : torque
$\cos\varphi$: power factor
P : load
b : saddle torque
I : current
n : speed
η : efficiency

Synchronous Motor





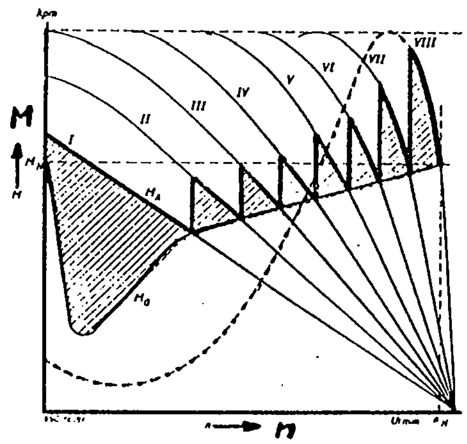


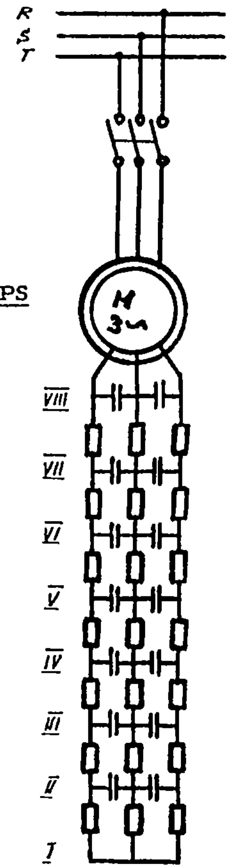
c) SLIP RING MOTOR

Construction

- The slip ring motor is like the squirrel cage motor an induction motor
- Its rotor windings are brought out to slip rings which allows to control the starting torque and current within a wide range.

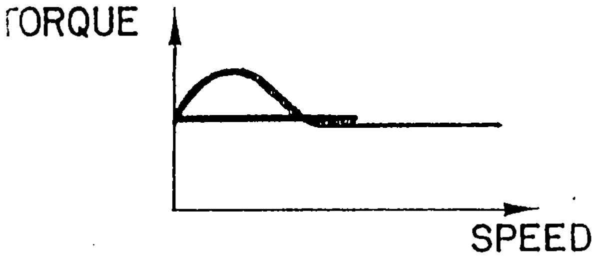
START OF A SLIP RING MOTOR WITHIN EIGHT STEPS



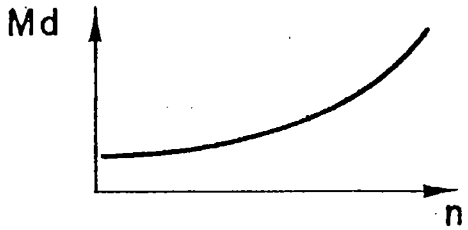


MN Nominal torque
MA Torque characteristics during start up
MG Torque of the load

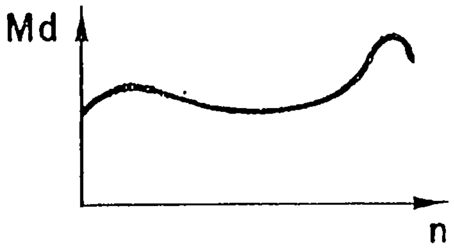
TYPICAL TORQUE / SPEED CURVES



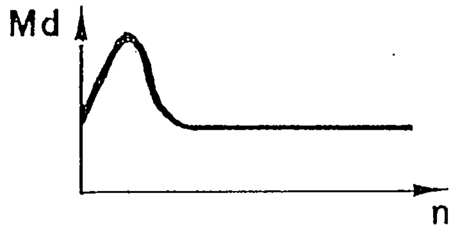
CONVEYOR BELT



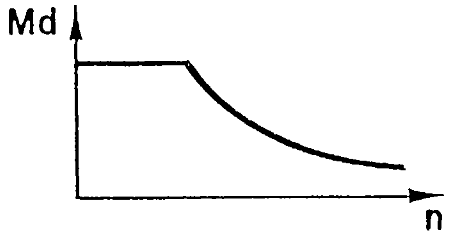
FAN



TUBE MILL

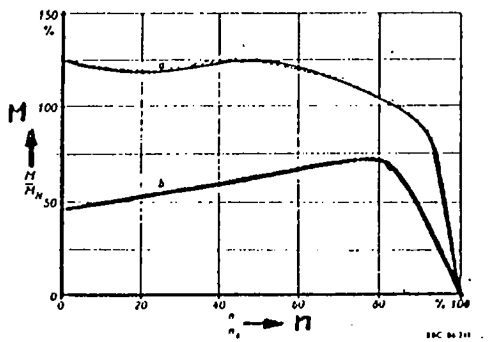


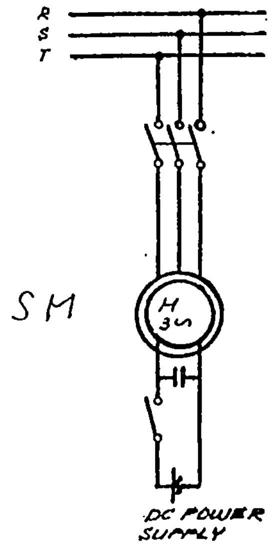
KILN



WINDER

STARTING CHARACTERISTIC



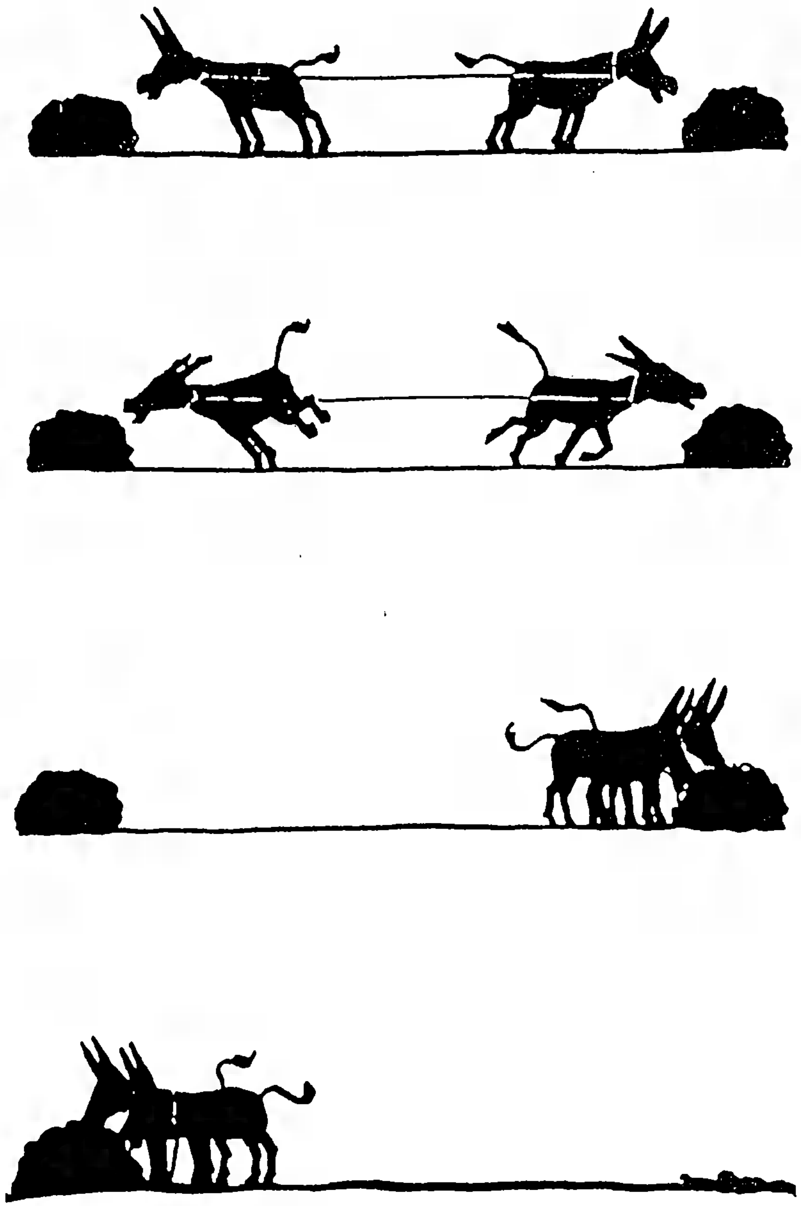


M Torque

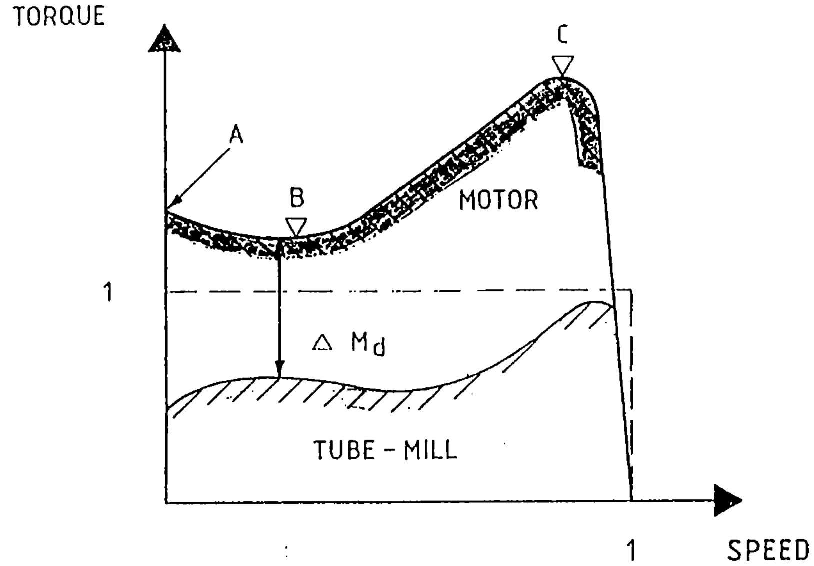
N ~~M~~ Speed

a) Motor with massiv poles and starting winding

b) Motor with lami - nated poles and starting winding



TORQUE / SPEED CHARACTERISTIC



A : STARTING TORQUE

B : SADDLE TORQUE

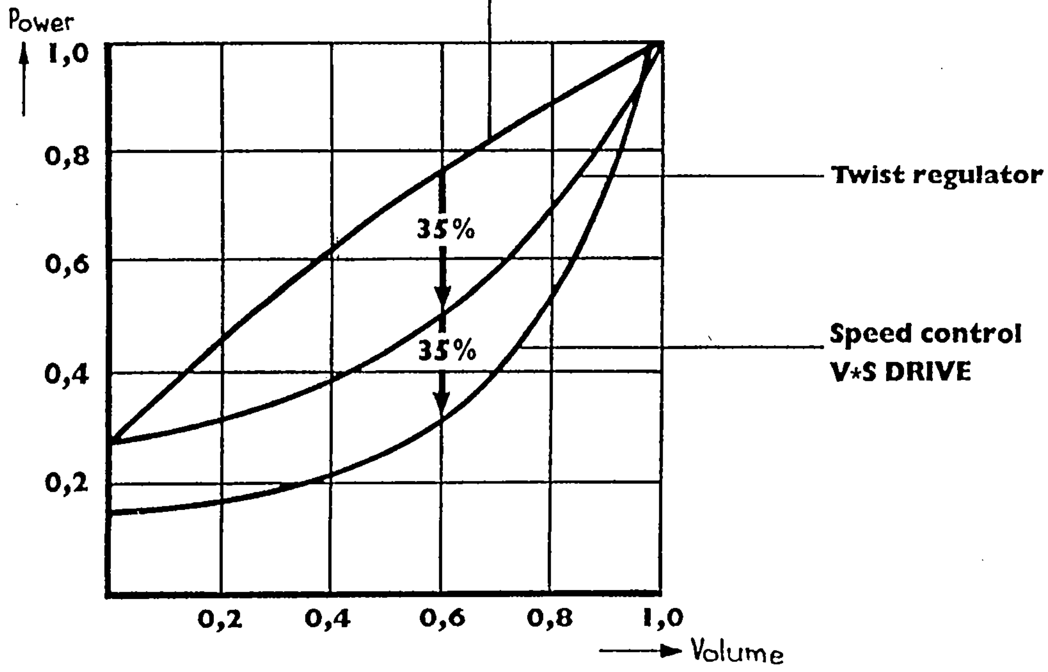
C : BREAK DOWN TORQUE

ΔM_d : TORQUE AVAILABLE FOR ACCELERATION

Application Examples

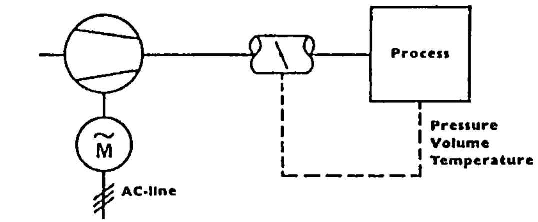
Helps to save energy

Example: Fan

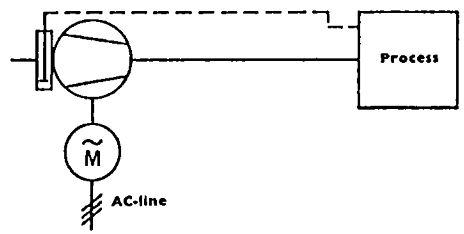


Ventilator

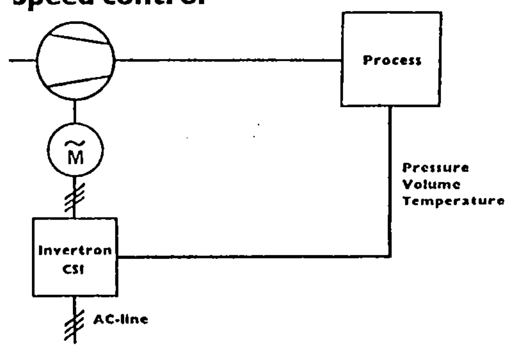
Throttle control



Twist control

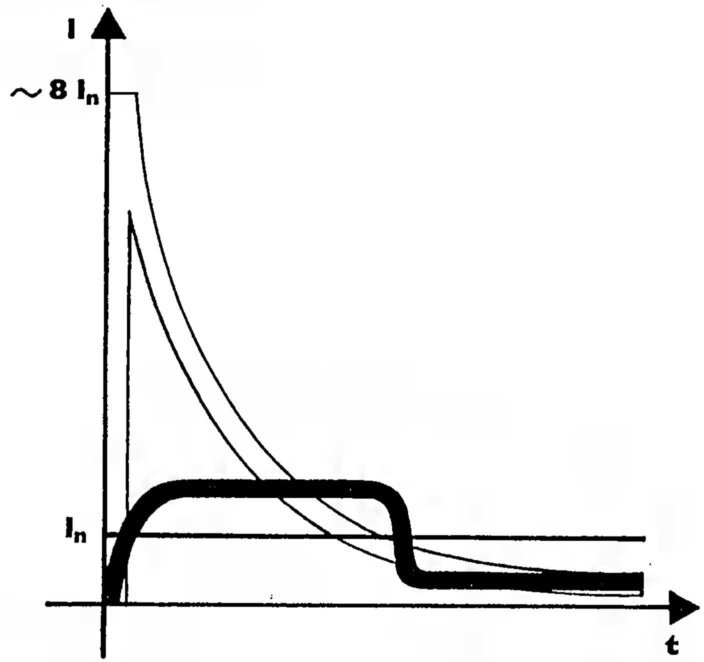


Speed control



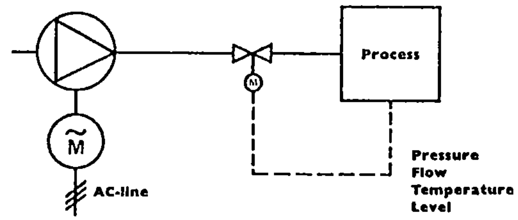
Application Examples

Reduces Starting Current
Reduces Mechanical Wear

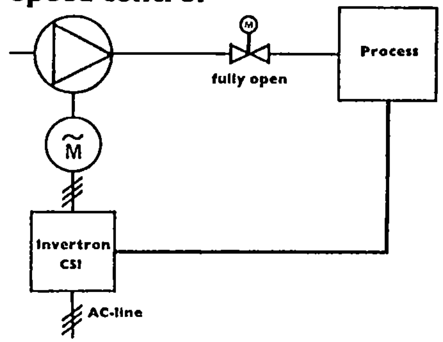


Pumps

Throttle control

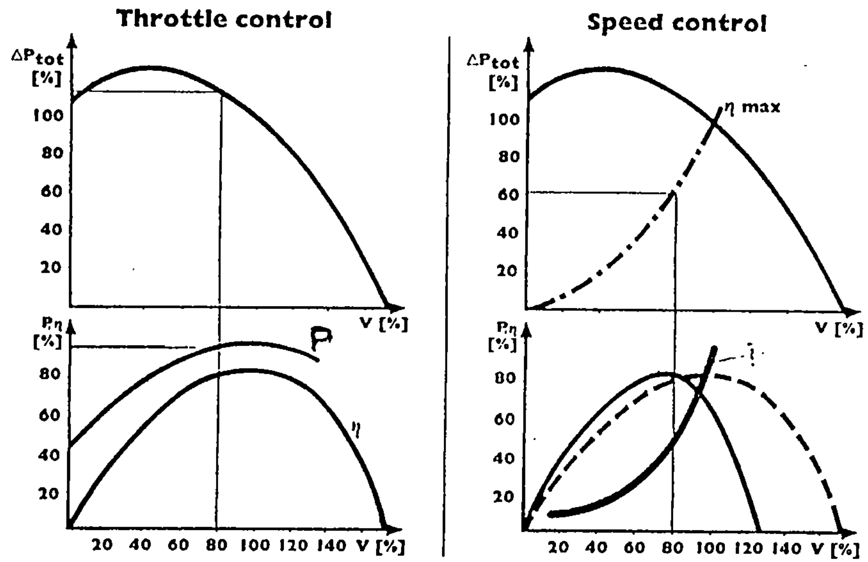


Speed control



Application Examples

Ventilator



$$\boxed{P = \frac{V \cdot \Delta P_{tot}}{\eta}}$$

Example: Volume of flow: 80 %, Drive power: 100 kW, Running hours: 8000, kWh-cost: £ 0,042

$$P_{80} = \frac{P_{100} \cdot 0{,}8 \cdot 1{,}12}{0{,}94} = P_{100} \cdot 0{,}95$$

$$B_K = 95 \cdot 8000 \cdot 0{,}042 = \underline{£\ 31\,920}$$

$$P_{80} = \frac{P_{100} \cdot 0{,}8 \cdot 0{,}6}{0{,}94 \cdot 0{,}95} = P_{100} \cdot 0{,}53$$

$$B_K = 53 \cdot 8000 \cdot 0{,}042 = \underline{£\ 17808}$$

Savings on energy costs:
14 112 £/year

Outstanding Advantages of Variable Speed Drives

- Optimal process control

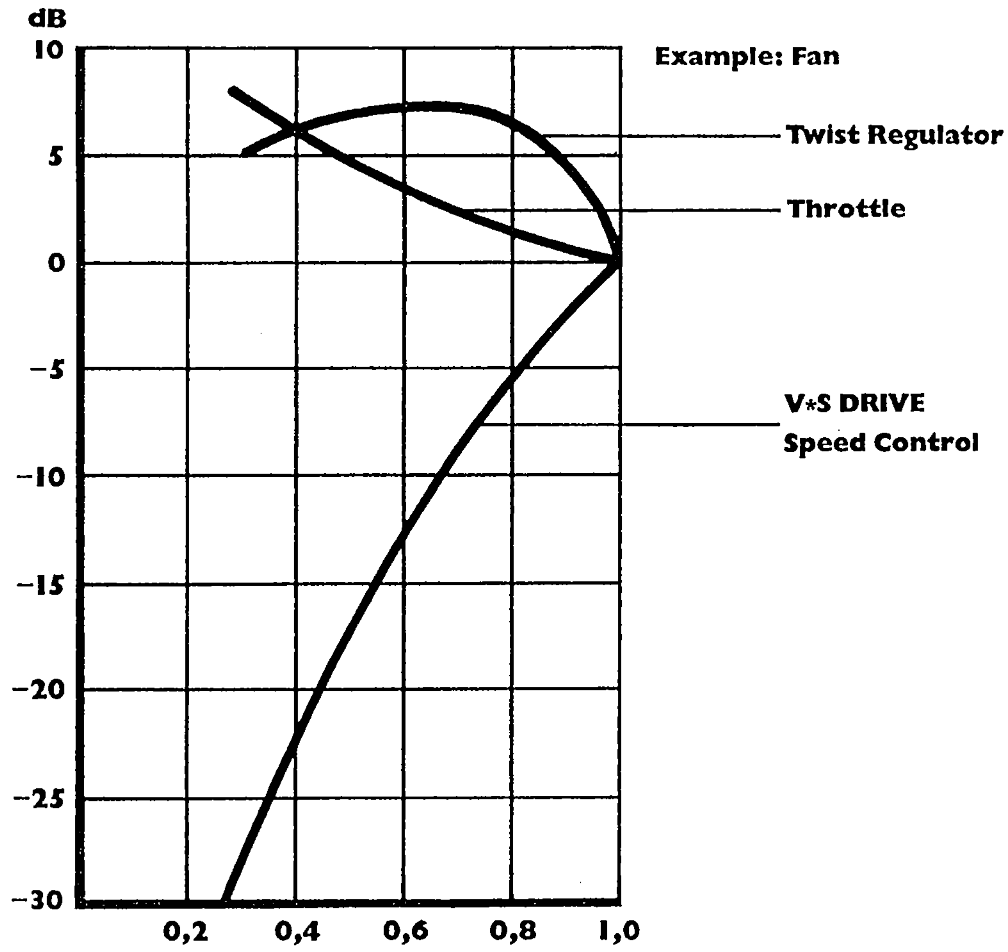
- Reduced stress on machines and supply system during starting

- Better utilization of the primary energy owing to the higher total drive system efficiency

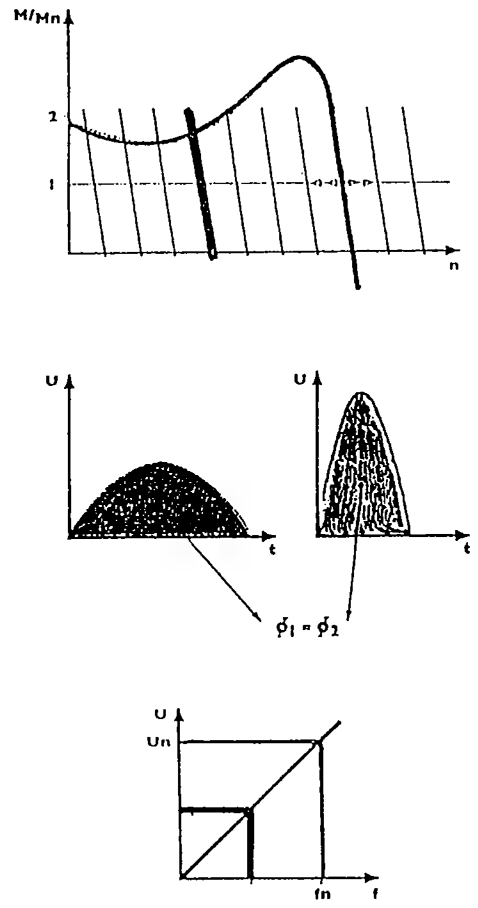
Drive Specification

- Robust
- Ease of maintenance
- Reliability
- Efficiency
- Investment cost

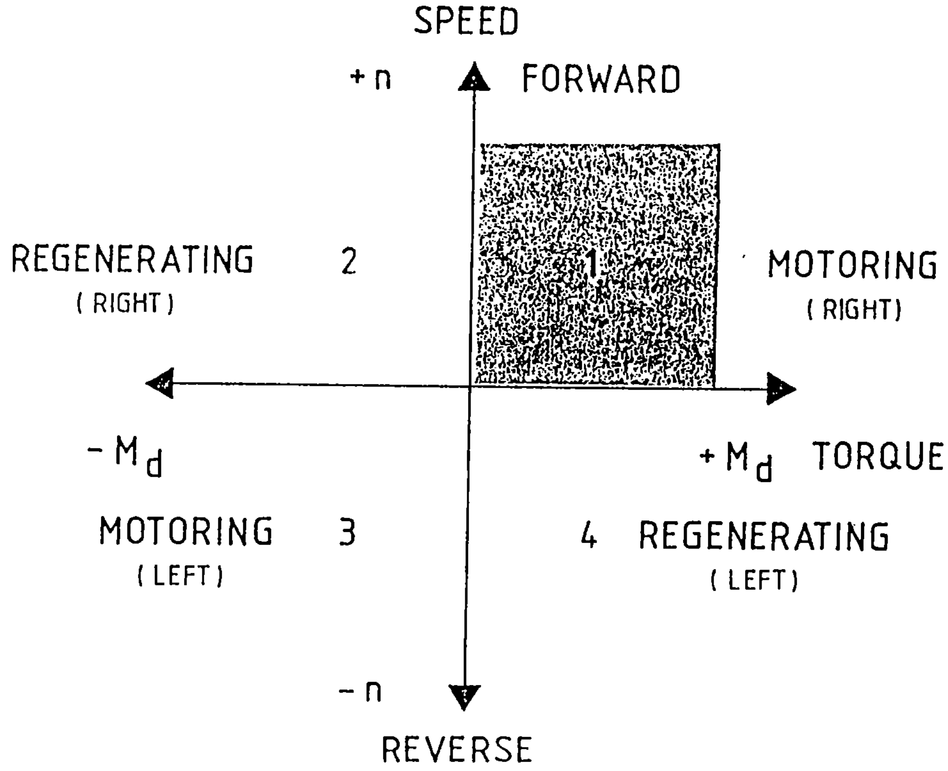
Reduces Noise



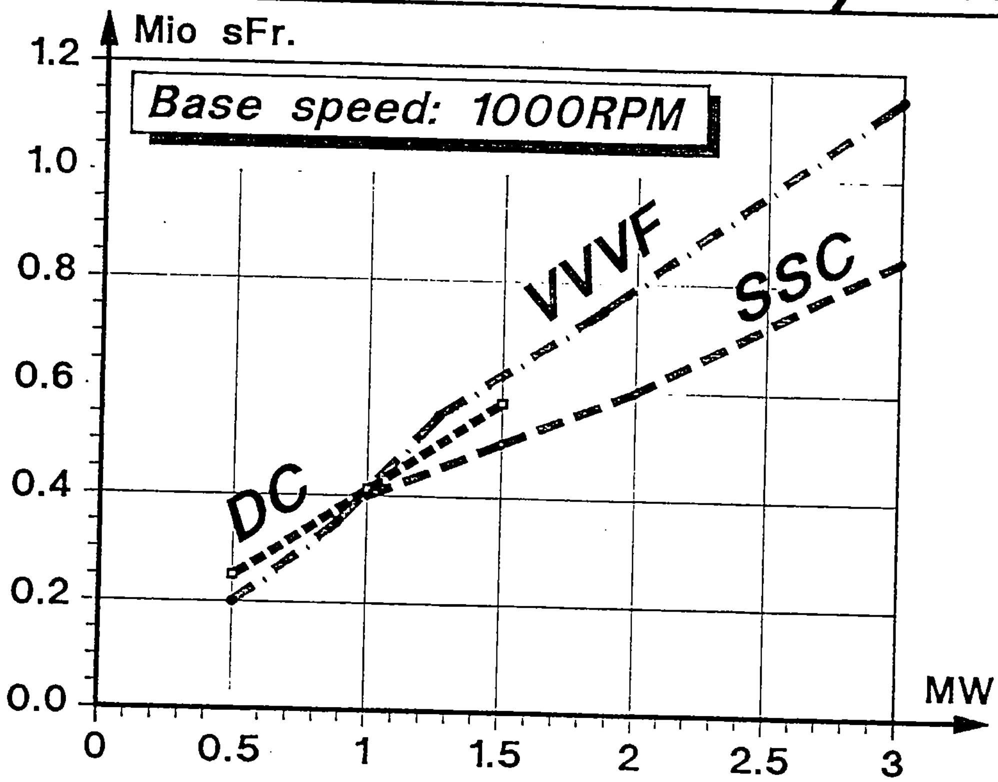
Torque curves of an AC-Motor at variable frequencies



SPEED / TORQUE (4 QUADRANTS)

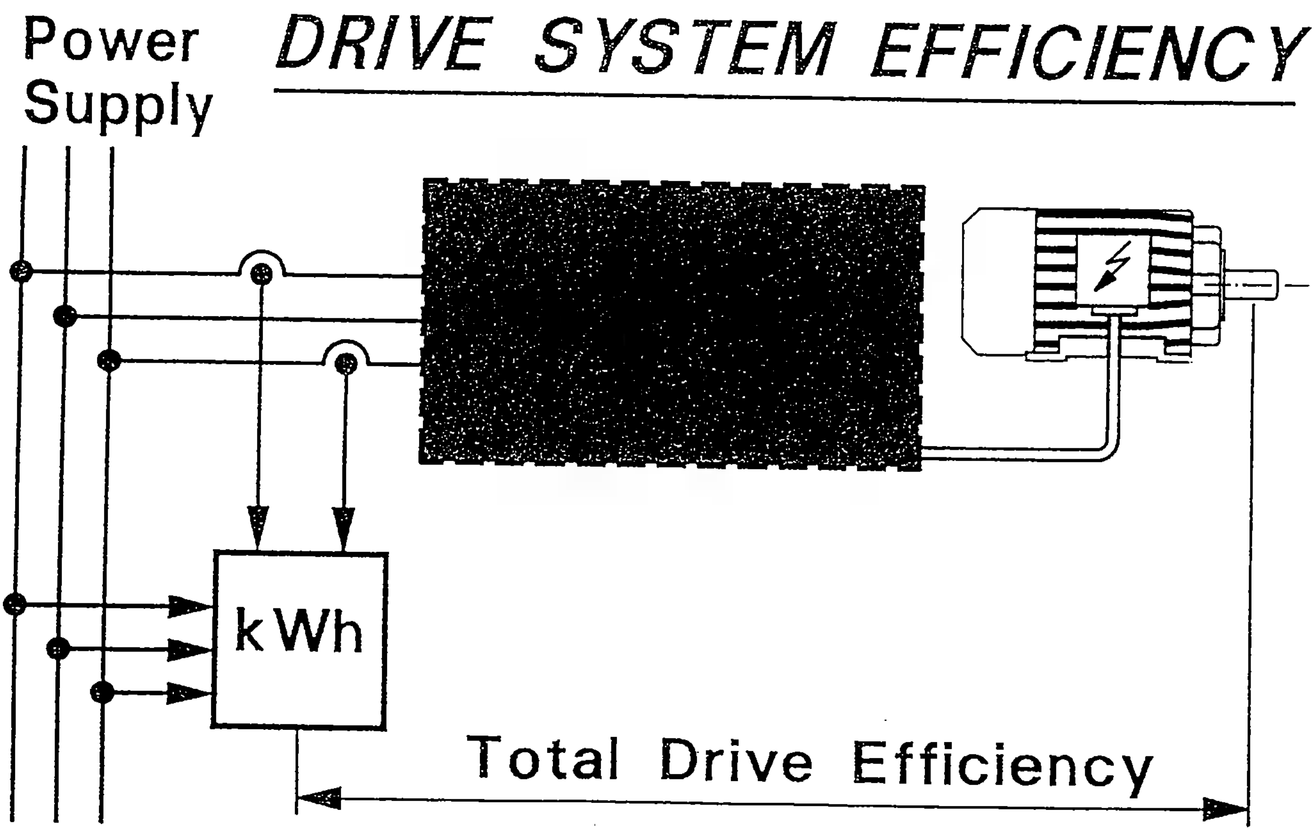


Budget Prices for Variable Speed Drive Systems



E410007 "HOLDERBANK"

DEFINITION OF TOTAL DRIVE SYSTEM EFFICIENCY

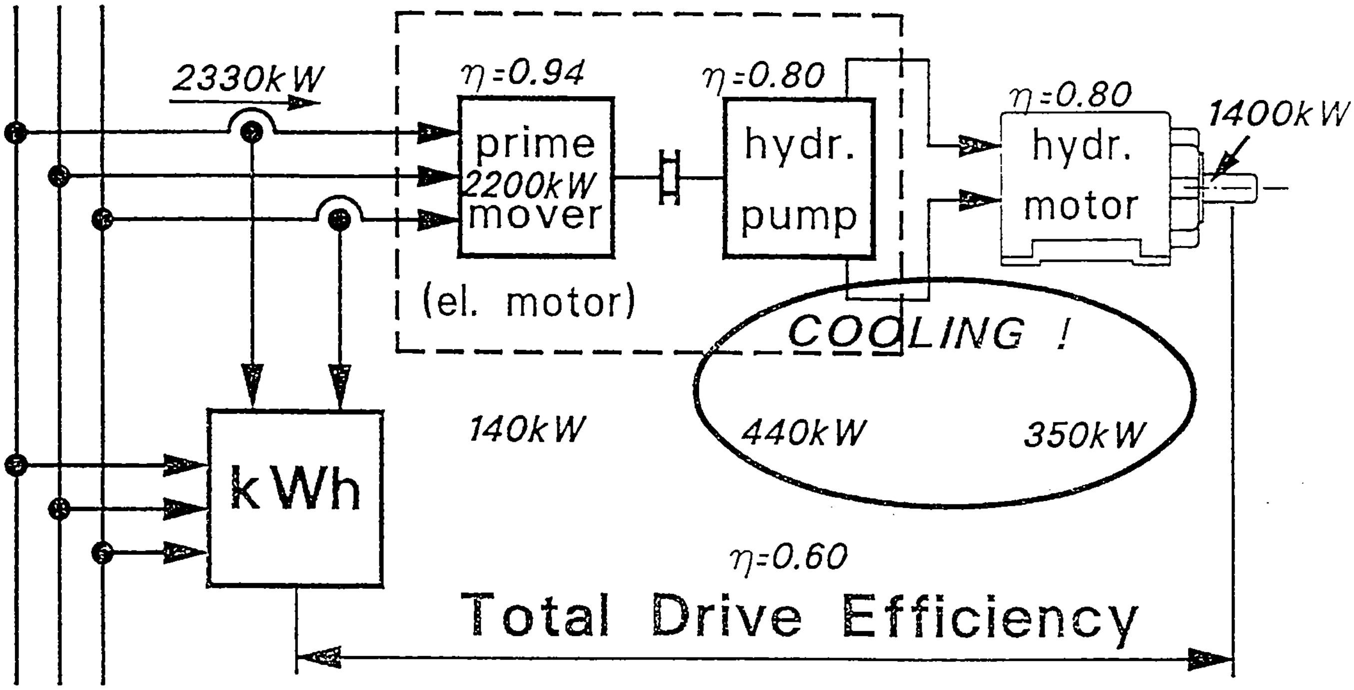


"HOLDERBANK"

E49593–1 21.1.92 ip/Rü

MAIN COMPONENTS OF A HYDROSTATIC VARIABLE SPEED DRIVE SYSTEM

Power Supply

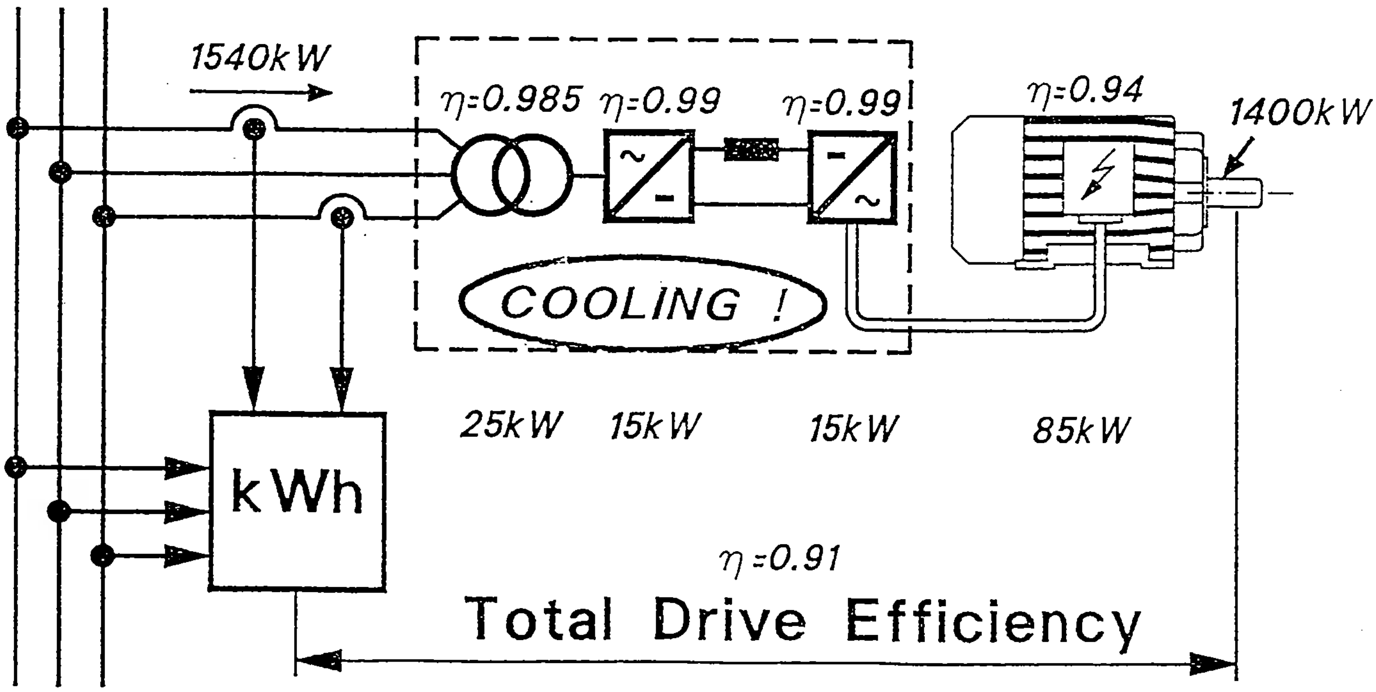


Answer

E49593-3 17.2.92 lp/Rü

MAIN COMPONENTS OF A VVVF TYPE VARIABLE SPEED DRIVE SYSTEM

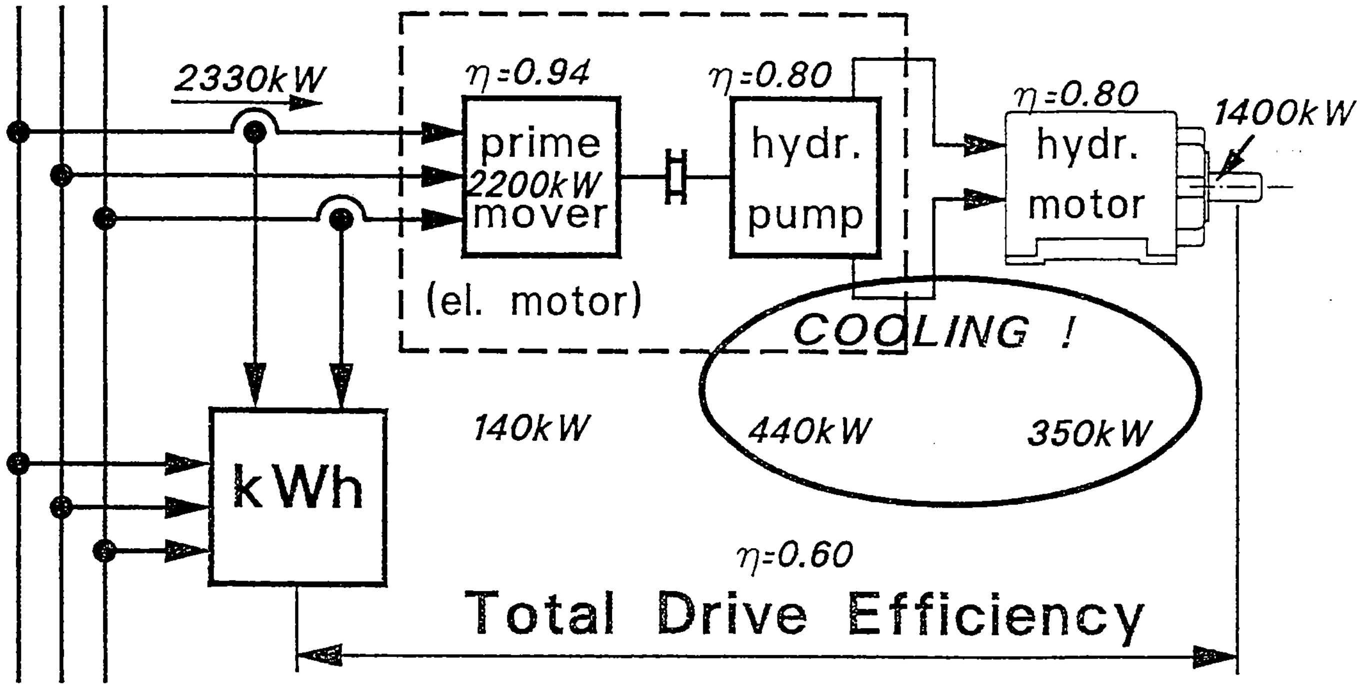
Power Supply



Answer

MAIN COMPONENTS OF A HYDROSTATIC VARIABLE SPEED DRIVE SYSTEM

Power Supply



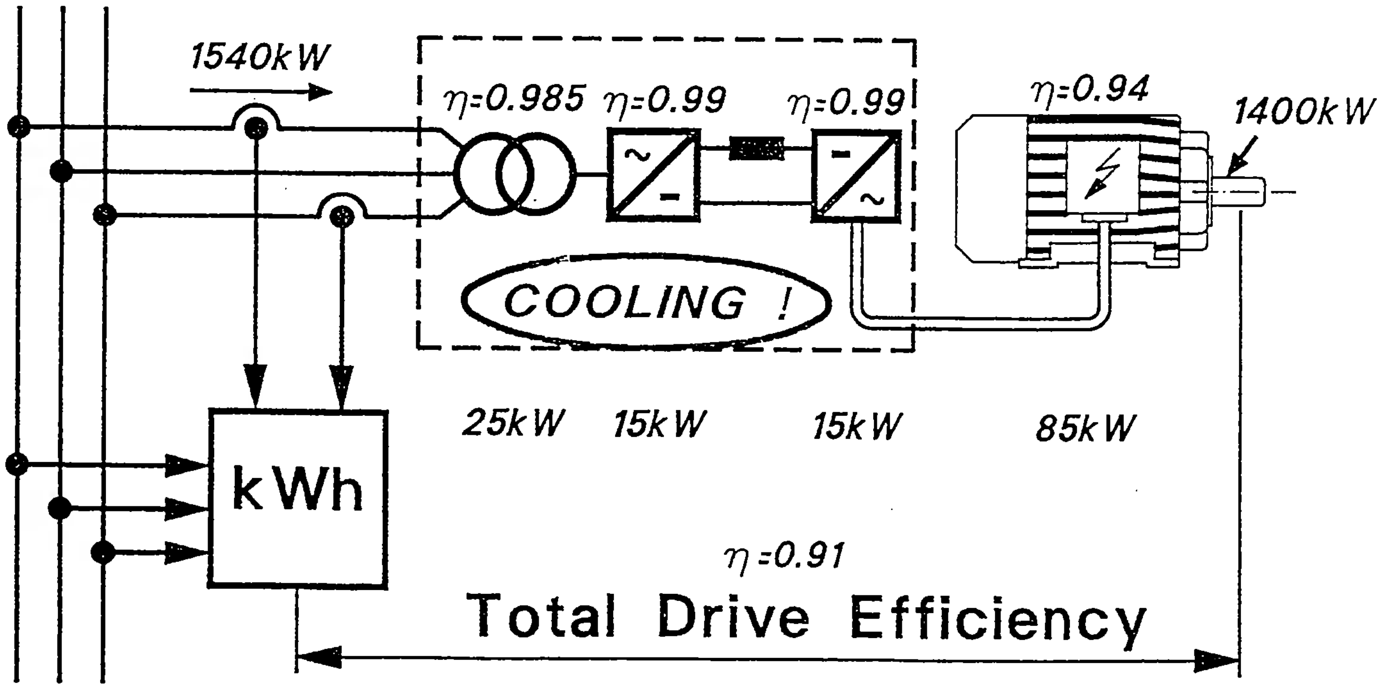
"HOLDERBANK"

Answer

E49693-3 17.2.92 lp/Rü

MAIN COMPONENTS OF A VVVF TYPE VARIABLE SPEED DRIVE SYSTEM

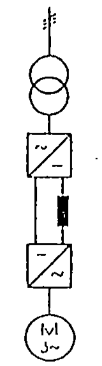
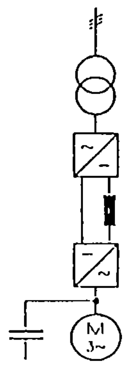
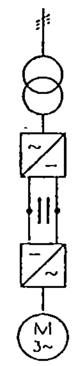
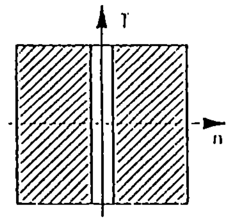
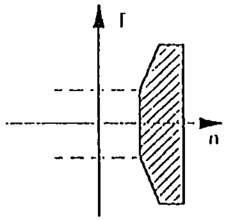
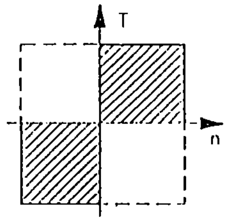
Power Supply



"HOLDERBANK"

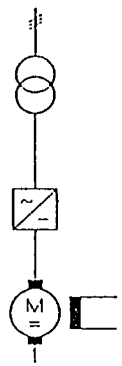
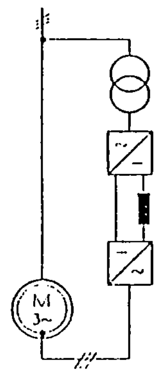
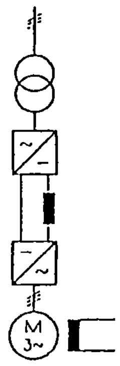
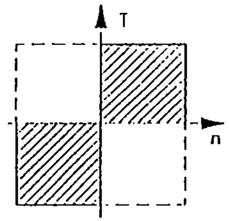
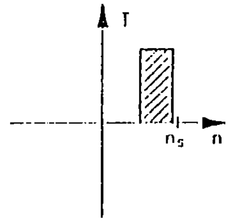
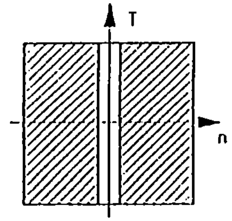
SUMMARY OF LARGE VARIABLE SPEED DRIVE SYSTEMS FOR THE CEMENT INDUSTRY (> 1MW)

(based on cage induction motors)

Drive system	Current-source inverter-fed induction motor	Load-commutated inverter-fed induction motor	Voltage-source inverter-fed induction motor (PWM)
System diagram			
Type of machine	Cage induction motor		
Operating range T: torque n: speed			
Typical power range	up to 2000kW	500 ... 5000kW	800 ... 5000kW
Typical speed range	2 ... 100%	65 ... 100%	0 ... 100%
Significant properties	Single-motor drive of medium power Applicable normally for loads with squared torque/speed characteristic	Single-motor drive with nearly sinusoidal motor current and voltage Applicable normally for loads with squared torque/speed characteristic	Single- or multi-motor drive Good performance also at low speeds Power-factor to line nearly unity
Suitable for	Fan	Fan	Fan, (Kiln)
Price [%] Base: 1500kW/1000RPM	105%	110%	110%

SUMMARY OF LARGE VARIABLE SPEED DRIVE SYSTEMS FOR THE CEMENT INDUSTRY (> 1MW)

(based on other than cage induction motors)

Drive system	Direct Current Drive	Wound-rotor induction motor with subsynchronous converter cascade	Converter-fed synchronous motor
System diagram			
Type of machine	Direct Current Motor	Wound-rotor induction motor	Synchronous machine
Operating range T: torque n: speed			
Typical power range	up to 2000kW	500 ... 5000kW	1000 ... 10000kW
Typical speed range	0 ... 100%	50 ... 95% of synchronous speed	(0) .. 10 ... 100%
Significant properties	Single-motor drive of medium power Good performance also at low speeds	Slip-power recovery Economic for small motor-speed-control-range High starting torque Suitable for retrofitting of existing slipring motors	Single-motor drive of high power High speed possible
Suitable for	Fan, Kiln	Fan	Fan
Price [%] Base: 1500kW/1000RPM	100%	85%	140%

Scenario of the example

A 1400 kW kiln fan drive operates at 80% of the nominal speed.
The required driving power at the fan shaft is, therefore, 720 kW.

	Drive 1	Drive 2
Type	hydraulic	electrical
Investment cost	240'000 US $	340'000 US $
Total losses	220 kW	100 kW
Total efficiency	(76%)	(87%)
Cost per kWh	4.2 US cents	4.2 US cents
Rate of kWh cost increase	4% p.a.	4% p.a.
Rate of interest	7% p.a.	7% p.a.

The systems are assumed to be in operation for 7000 hours per year.

PA/Rüe/gsr
March 92

The Energy Saver

1 **Saves Electrical Energy on Pumps and Fans typically 20 to 40%!**

2 **Allows Optimization in Process Installations. Much is to be discussed with your specialists.**

3 **Reduces peak currents when AC-Motors are started. Your electricity supply company will be grateful!**

4 **Reduces mechanical wear. You save twice!**

5 **Reduces Noise. Your plant operators will be grateful for that, often also your neighbours!**

6 **Can be retrofitted to existing AC-Motors. This, of course, requires space and cabling**